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# SUMMER REGIMES


by

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# REVIEW AND APPROVAL PAGE

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13. Abstract: This technical note presents a back-to-basics approach to forecasting the weaker, slower moving weather systems of summer. It is especially designed for new and inexperienced forecasters, but it is also an excellent review for all forecasters. As summer approaches, the subtropical ridge begins to drift northward across the southern United States. The increasing insolation, moisture, and weakening pressure and thermal gradients require forecasters to apply different forecasting rules. This technical note presents synoptic patterns and regimes that routinely occur during the summer months. Synoptic pattern recognition is still one of the most important considerations when producing a forecast and will help in determining if model guidance is "on track."

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# PREFACE

This technical note is the first of the four forecaster memos being revised and updated with later model guidance and satellite images. These seasonal weather patterns were originally published by Third Weather Wing in the early 1980s.

The information presented within this technical note is a cumulation of weather information that I have gained over 27 years as an Air Force weather forecaster, and after retirement, 16 years as a Civil Service Lead Forecaster in the Severe Weather Section of the AFGWC, and now AFWA's Production Floor.

I gained considerable knowledge over the 16 years in the Severe Weather Section while observing weather conditions across the continental United States in preparation of Military Weather Warning Advisories (MWAs) and also the issuance of Point Weather Warnings (PWWs). Certain weather patterns for each season routinely occurred. I learned to spot evolving weather events across the country using the severe weather analysis package, satellite photos and model guidance. Being a "pack rat," I have collected certain significant weather events, which helped tremendously in preparation of this technical note.

This technical note presents a back-to-basics approach to forecasting the weaker, slower moving weather systems of summer. It is especially designed for new and inexperienced forecasters, but it is also an excellent review for all forecasters. As summer approaches, the subtropical ridge begins to drift northward across the southern United States. The increasing insolation, moisture, and weakening pressure and thermal gradients require forecasters to to shelve their winter rules and adjust to the changing summer systems.

This technical note is basically composed of synoptic patterns and regimes that routinely occur during the summer months. Synoptic pattern recognition is still one of the **most important** considerations when producing a forecast and will help in determining if model guidance is "on track." I believe this technical note will help future forecasters for years to come regardless of any new numerical model improvements and/or new systems that will come on line.

# ACKNOWLEDGMENTS

Special acknowledgments goes to Air Force Weather Agency's Commander and Senior Staff for funding and allowing me to continue part-time writing and publishing Technical Notes (after Civil Service retirement). This part-time position is managed through Science Applications International Corporation (SAIC).

Special thanks goes to Thomas K. Klein Sr., Colonel (ret), Offutt AFB, SAIC Site Manager, for his advice and encouragement during this transition from operational weather forecasting to research and writing as part of AFWA's DNTT section.

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Thanks to the rest of the DNTT personnel for their help: Master Sergeant Ron Bridges and Master Sergeant Gary Mercer.

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Finally, I acknowledge my wife, Doris, for her continued understanding of my interest in my profession even after retirement.

**EUGENE M. WEBER**

*Summer Regimes*

**Chapter 1**

# Introduction

*The key to successful summertime severe thunderstorm forecasting is, as always, meticulous attention to detail (from AWSTR 200 (Rev).*

The following synoptic regimes and comments are intended to remind forecasters of summer month phenomena. By early summer, the fast-moving systems of spring are replaced by sluggish and stagnant weather systems as the polar jet stream moves northward into the northern CONUS and Canada. The subtropical ridge shifts northward and becomes the dominant weather system across the central and southern CONUS. Consequently, trough contour and thermal configurations become increasingly weaker. Severe thunderstorms, accompanied with hail and strong surface winds, and especially heavy rainfall, often develop within weak troughs and cold pockets. The quote from AWSTR 200 (Rev) shown above is so important during the weak gradients of summer – **meticulous attention to detail!** Additionally, low-level moisture and instability generally exist, and combined with surface heating, frontal and convergence zones, sea/land breezes and orographic lifting, thunderstorms may occur over many areas of the CONUS and adjacent water areas as shown in the Cover Figure. Considerable discussion on the position of the subtropical high and its effects on summer weather will be presented.

# Upper Levels

**General.** A northward shift of the general circulation continues through July. Jet stream systems become weaker and extend west to east across the Gulf of Alaska, Canada and the northern CONUS by midsummer (see Figure 2-1).

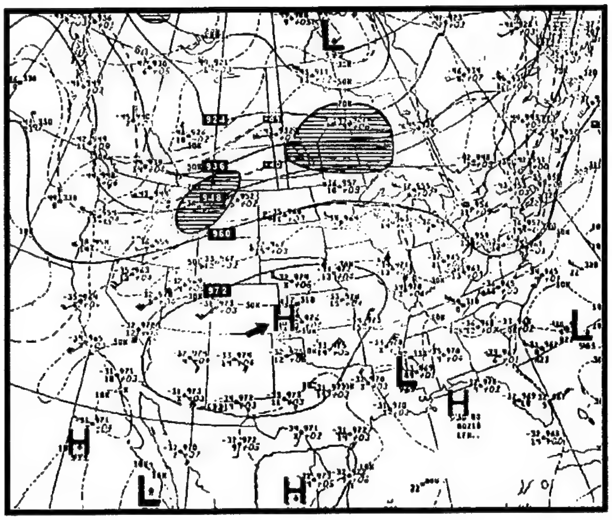


**Figure 2-1. 300-mb Analysis, 0000Z/18 July 1985.** The Polar jet is over northern CONUS/southern Canada.

Similarly, surface lows and their associated frontal systems track across the northern CONUS and Canada (Figure 2-2) when the subtropical ridge is in place across the central and southern CONUS (see subtropical high, noted by arrow in Figure 2-1).

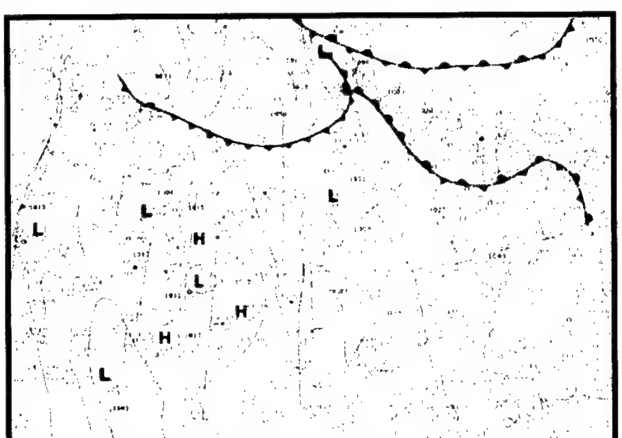

**Figure 2-2. Surface Analysis, 0600Z/30 July 1999.** Polar frontal systems are depicted across the northern CONUS.

**Subtropical High Locations (500 mb).** Cold fronts will move southward into the southern Great Plains and southeastern CONUS when steering winds are from a northwesterly direction (usually on the eastern side of the subtropical ridge; see Figures 2-3 and 2-4). East–west subtropical ridging becomes pronounced over much of the central and southern CONUS by July.

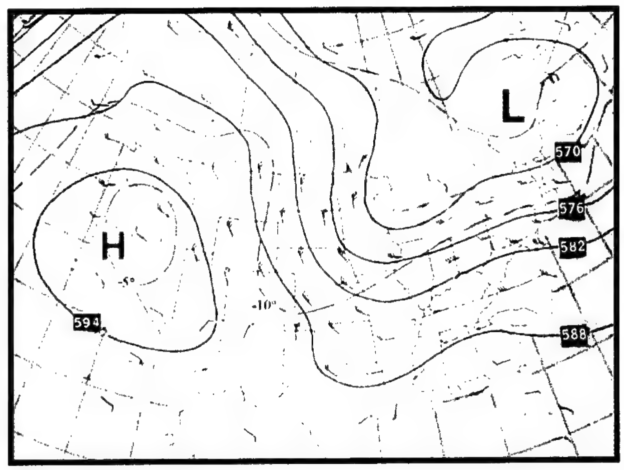


**Figure 2-3. 500-mb Analysis.** Subtropical high is located over the western CONUS.

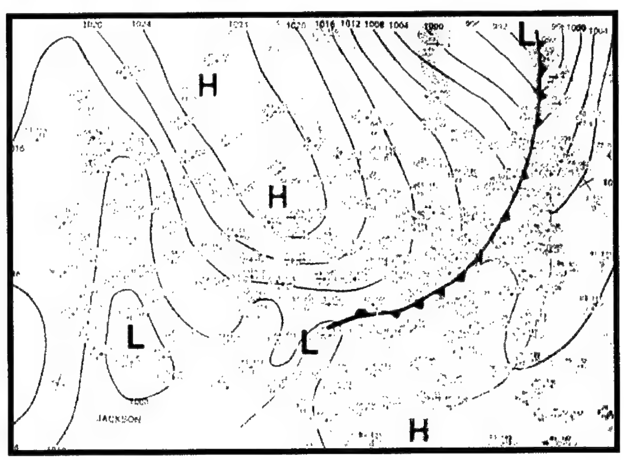


**Figure 2-4 Surface Chart.** Cold front moves into the southern and eastern CONUS.

Within this ridge, embedded high(s) appear over areas of the CONUS as shown in Figures 2-5 to 2-7. These ridges/highs may remain quasi-stationary for several days before flattening or shifting to another part of the country due to changes in the upper air pattern. Maintaining continuity on location(s) of subtropical high(s) for progging frontal movements and for steering

convective weather systems within the weak flow of ridges **becomes most important**. See Figure 2-8 that follows on page 2-3.

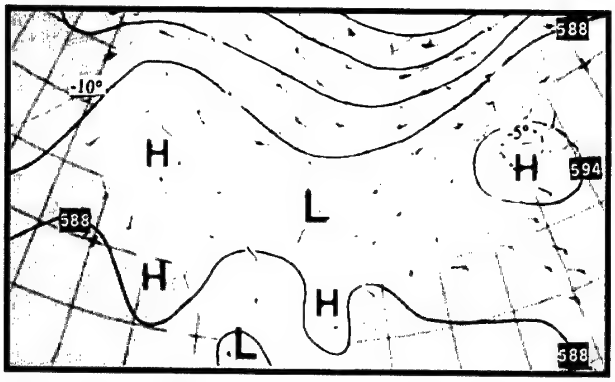


**Figure 2-5. 500-mb Analysis.** Subtropical high over the western and eastern CONUS.

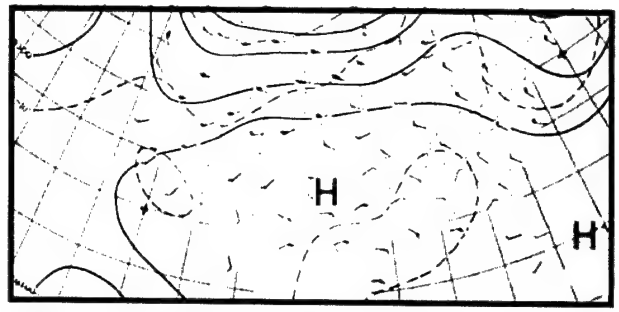


**Figure 2-6. 500-mb Analysis.** Subtropical high over the central CONUS.

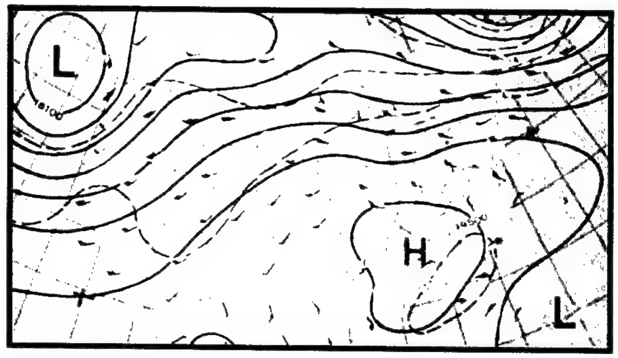


**Figure 2-7. 500-mb Analysis.** Subtropical high over the eastern CONUS.

The model shown in Figure 2-8 depicts a typical subtropical high regime across the CONUS during midsummer. The strengthening subtropical high is responsible for several significant weather events that occur during the summer months. In Figure 2-8, the subtropical high center is located over the central Great Plains. The monsoon season extends over a large area of the western CONUS to the Rocky Mountains. A heat wave and capping of convection prevails over the Great Plains. Quasi-stationary fronts (frontal waves and severe thunderstorms) stretched east-west across the northern Rocky Mountains and Great Plains. Cold fronts and associated severe thunderstorm events dropped southeastward over the Great Lakes and northeastern CONUS within upper-level northwest flow. Diurnal air mass and sea breeze thunderstorms affect the southeastern and southern CONUS. These regimes will be presented and discussed throughout the rest of this publication. Again, it is emphasized that forecasters **maintain day-to-day continuity** on the subtropical high's position for steering convective weather and frontal systems. Several high centers may appear on the 500-mb chart and on the model runs; however, in most cases, only one or two warm-core high cell(s) will appear at the 300-mb level and above. Subtropical highs persist over any given area for weeks at a time, and depending on your location in respect to the high, you may experience heavy orographic rains, a prolonged heat wave, or frequent severe thunderstorms/heavy rainfall occurrences within northwest flow. The model shown is popularly called the "Ring of Fire" by

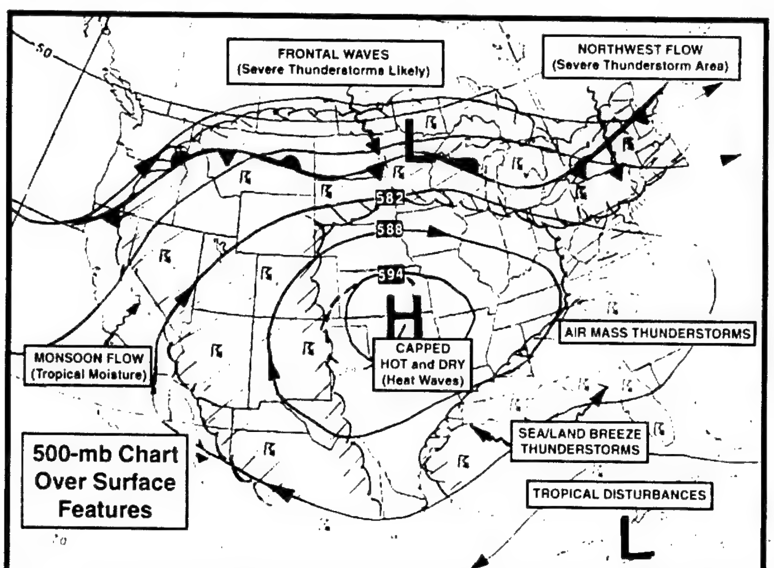


**Figure 2-8. Model.** The thunderstorm areas shown do not always occur simultaneously–the intent of this model is to show potential areas of development.

forecasters – thunderstorms surround the capped area. Figure 2-8a shows lightning strikes associated with the thunderstorm activity.

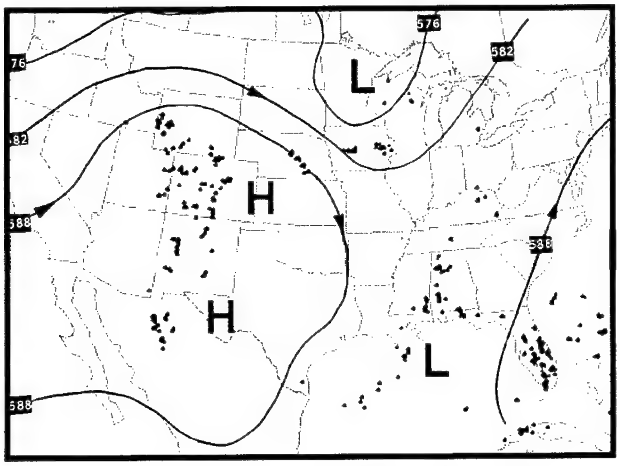


**Figure 2-8a. Lightning Strikes at 2015Z/26 July 2000.** Figure 2-8a depicts mid-afternoon positive (blue) and negative (red) strikes around a subtropical high in the southern Great Plains. Monsoonal strikes are shown over the Rocky Mountains. Strikes over Nebraska and Iowa are along a stationary front. Air mass and sea breeze lightning strikes are shown over the southeastern CONUS.

**Weak Pressure and Thermal Patterns.** With increased ridging, the cyclonic flow of winter and spring is replaced by weaker height, wind and thermal troughs. Large-scale cyclonic flow is generally confined to areas above 45° north. Forecasters should closely follow weak pressure and thermal troughs especially when moist and unstable air is noted. Weak PVA, cold air advection, cold pockets and upper lows can steepen lapse rates within a moist and unstable air mass.

Computer analyses within ridge areas may miss weak wind, thermal and height troughs embedded within the synoptic flow. Analyses are drawn for standard height and temperature isolines. If weak thermal and height gradients exist, a weak trough may appear between standard analyzed isolines. Figures 2-9 and 2-11 depict a developing trough over the upper Midwest that the models missed. Thunderstorms developed across eastern South Dakota/Nebraska and spread across Iowa/Minnesota. Rochester, Minn. was deluged with seven inches of rain in less than six hours. In this case, a north-south stationary front was located across the central Plains. Figures 2-9 and 2-10 show winds that cross the contour (height) flow. This is the first clue that a weak trough may either exist or is developing within the weak flow. Note wind direction reported respectively by Huron, S.D. and St Cloud, Minn. (see arrows); the winds are blowing across the contours. Thermal troughs form over the upper Midwest and central Rocky Mountains to support the short wave (Figure 2-11).

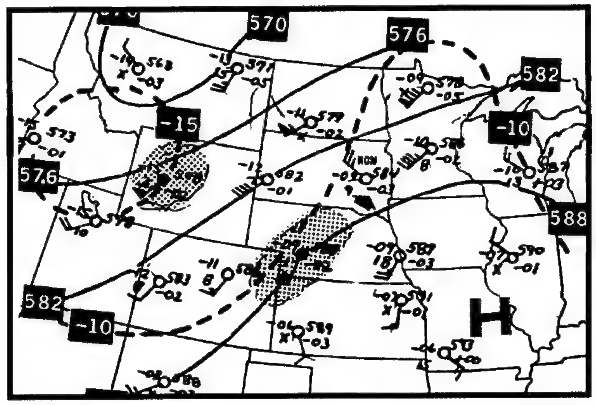


**Figure 2-9. 500-mb Analysis, 1200Z/6 July 1978.** Weak wind, thermal and height gradients.

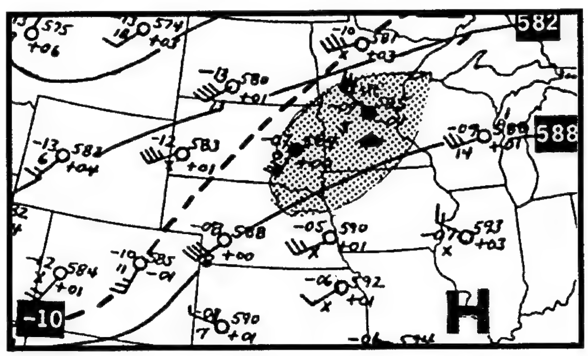


**Figure 2-10. 500-mb Analysis, 0000Z/7 July 1978, 12 hours later.**

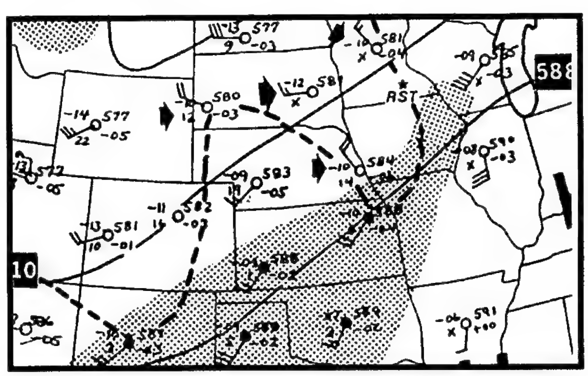


**Figure 2-11. 500-mb Analysis, 1200Z/7 July 1978.** Note continued northwesterly winds at Saint Cloud, Minn. and Omaha, Neb.

**Closed Lows.** Although an infrequent feature during the summer months, closed lows may develop within deepening troughs and are likely to remain stationary or drift slowly eastward. This event generally occurs east of the Rocky Mountains and is dependent on the position of the subtropical high (Upper troughs deepen on the east side of the high). In the following example, the subtropical high/ridge is located over the central and southern CONUS. The associated weather conditions with these upper lows are cool and cloudy with rain over a period of several days. The following sequence of events is presented, Figure 2-12 through 2-14.

In Figure 2-12, a developing short wave and associated jet max is moving southeastward across the Great Lakes. In the 500-mb analysis, Figure 2-13, the subtropical ridge stretches across the central and southern CONUS. Strong cold air advection for the season is located within the trough over the northern Great Lakes.

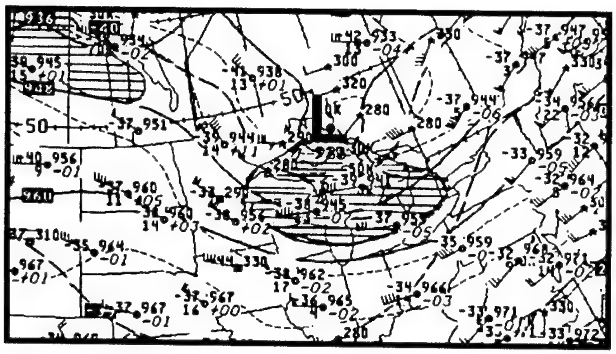

**Figure 2-12. 300-mb Analysis, 1200Z/9 August 2000.** A developing short wave is moving southeastward.

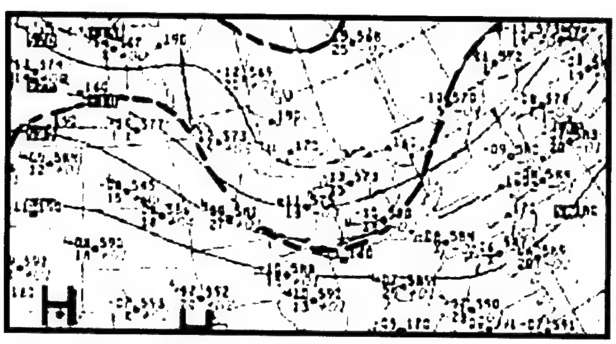

**Figure 2-13. 500-mb Analysis, 1200Z/9 August 2000.** Cold air advection, noted by the thermal trough, indicates further deepening.

Three days later, Figure 2-14, the East Coast trough has deepened and a closed low appeared over Pennsylvania. Cold, cloudy, wet weather prevailed across the northeastern CONUS. The satellite images, Figures 2-15a and 2-15b are included to show that thunderstorms will move southward when the upper flow is northerly. In Figure 2-15b (5-hours later), Tennessee Valley frontal thunderstorms moved south and merged with Gulf Coast thunderstorms.

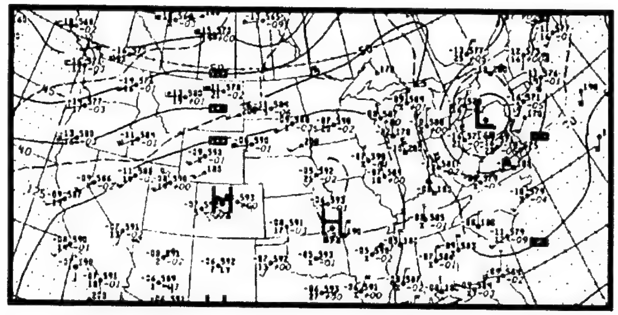

**Figure 2-14. 500-mb Analysis, 1200Z/12 August 2000.** A closed low has developed over the northeast.

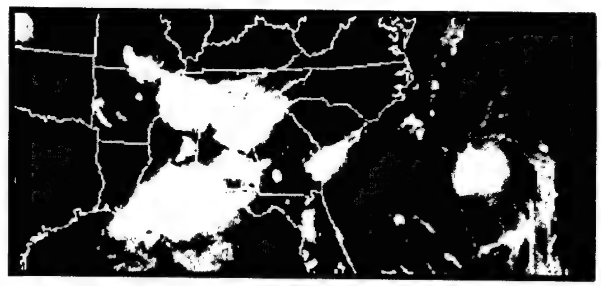

**Figure 2-15a. GOES East Infrared, 0045Z/11 August 2000.** Tennessee Valley thunderstorms move southward towards Gulf Coast sea breeze thunderstorms.

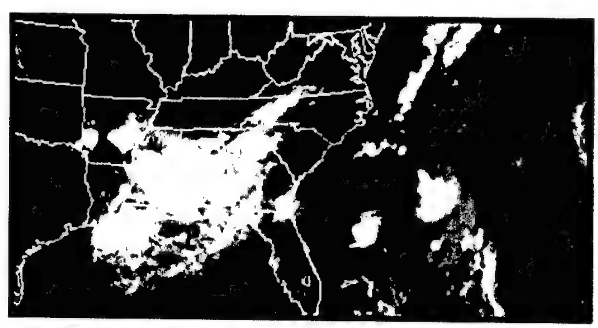

**Figure 2-15b. GOES East Infrared, 0545Z/11 August 2000.** The two thunderstorm areas have merged.

Closed lows within major troughs that either move toward or develop off the West Coast don't normally move inland (because of ridging) but move up the coast and often weaken. However, minor short waves and PVA lobes are ejected from these troughs to affect areas of the Great Basin and Pacific Northwest.

**Cutoff Lows/Cold Pockets.** Springtime cutoff low systems may continue into early summer prior to the intensification of ridges across the central and southern CONUS. With ridge intensification, however, upper lows and their cold pockets that do appear during summer are often small-scale systems but they often spawn widespread convective activity and rainfall. (Figures 2-16a and 2-16b) Cutoff lows such as shown in Figure 2-17 generally remain off shore due to the presence of the subtropical ridge over land.

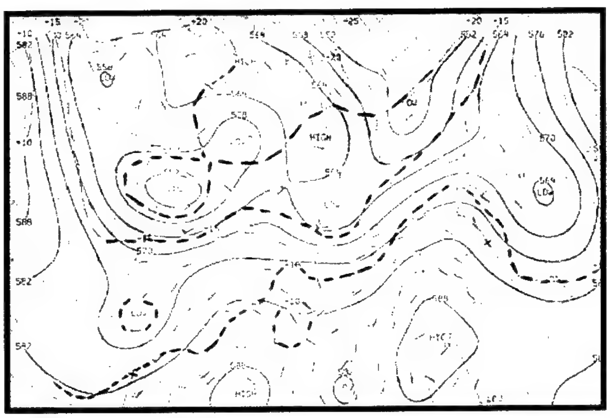

**Figure 2-16a. 500-mb Analysis, 0000Z/27 June 1989.** The figure shows weak lows and cold pockets.

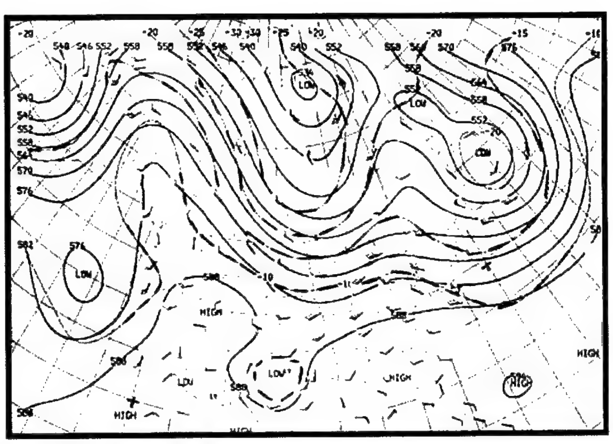

**Figure 2-16b. 500-mb Analysis, 1200Z/20 August 1986.**

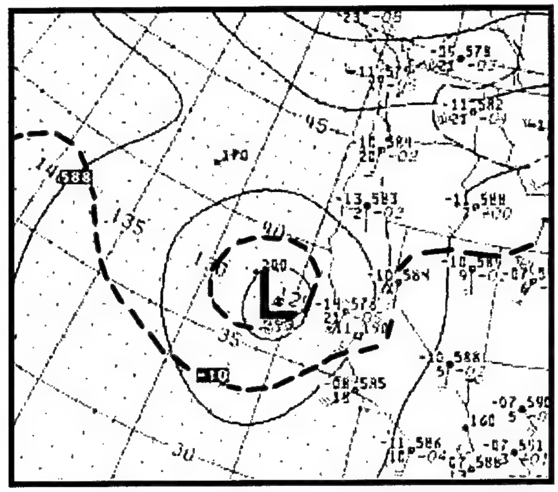

**Figure 2-17. 500-mb Analysis, 1200Z/09 August 2000.** The figure shows a stationary cutoff low.

Pockets of upper-level moisture appear almost daily on 1200Z analyses especially over the western CONUS. In many instances, these moisture pockets are a result of moisture lifted through convection from the previous afternoon and evening thunderstorms. The pockets often dissipate or shrink due to drying during the afternoon and often are not detected on 0000Z analyses. Don't attempt to forecast moisture advection unless a trough, cold air, PVA, etc. will sustain it. This cycle of increased moisture is often repeated.

Quoting from AWSTR 200 (Rev), "There is little doubt that the most destructive severe weather outbreaks in the summer are associated with southeastward moving surface cold fronts or a west-northwest or northwest flow in the mid-troposphere." This is true because weak, mid-level, short-wave trough systems move through or around ridges (generally in the divergent north to east sector) and trigger and enhance severe thunderstorms.

The rest of the information shown in this publication will be separated into regions.

*Summer Regimes*

**Chapter 3**

# Western CONUS

**General.** In early summer, strong Pacific storm systems are still possible from the Washington/Oregon to the northern Idaho/Montana border. By mid-summer, Pacific lows track across Canada; the associated polar cold fronts often dip southward into the northern CONUS. Generally, maritime polar (mP) cold fronts become stationary and aligned east to west across southern Wyoming, northern Utah and Nevada and interact with monsoon moisture (Figures 3-1 and 3-2).

The morning visible satellite picture, Figure 3-2, shows an east-west stationary front and associated cloud system from northern Nevada to Wyoming and Colorado.

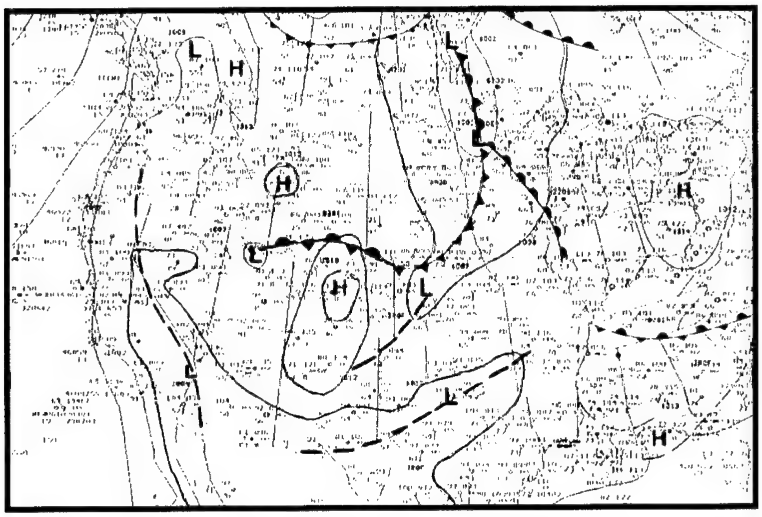

**Figure 3-1. Surface Analysis, 10 August 1999.** Cold front became stationary across central Rockies.

**Figure 3-2. Visible, 1630Z/25 July 1998.** The figure shows east-west frontal clouds. The arrow depicts south-to-north monsoon moisture.

## General

The second example, Figure 3-3, illustrates a typical summer regime. A strong low is noted over central Canada. The trailing cold front has moved into northeastern Montana as noted by the arrow. Cold frontal convection began over eastern Montana when the front encountered the monsoon moisture field shown over the majority of the western United States.

**Figure 3-3. Visible, 0000Z/20 July 1985.** The figure shows a cold front over Montana and an extensive monsoon cloud system.

**Thermal Low and Coastal Stratus.** The thermal low, located in the interior areas of California, western Arizona and Nevada, reaches its maximum strength in July (Figure 3-4a). Additionally, the North Pacific high continues to strengthen (Figure 3-4b). The pressure gradient along the West Coast increases due to interactions between these two systems and sets up an on shore gradient south of 40°N. Extensive low stratus ceilings are common along the West Coast through September (Figure 3-4c).

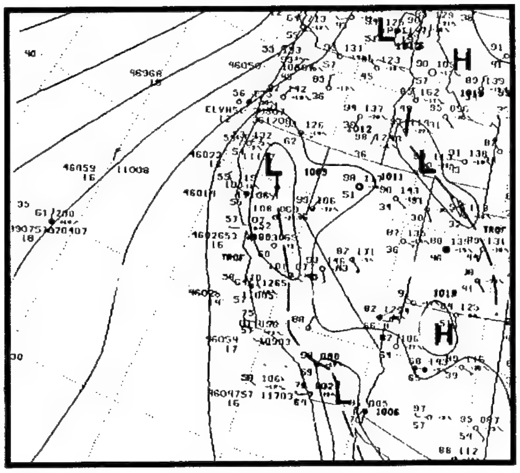

**Figure 3-4a. Surface Analysis, 0000Z/13 July 1999.** Thermal trough with heat lows over central California.

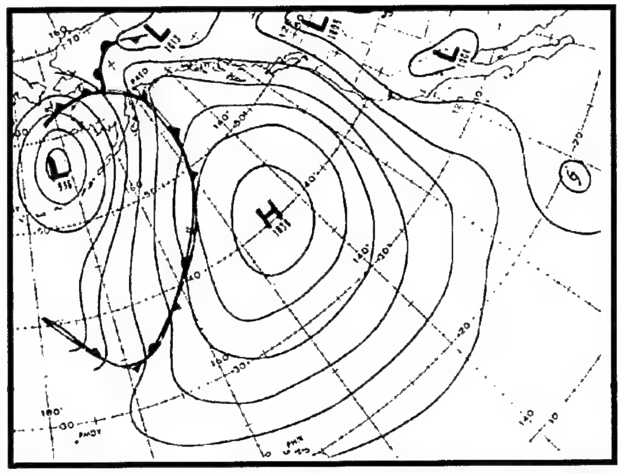

**Figure 3-4b. Surface Analysis, 0000Z/10 July 1978.** North Pacific high strengthens during summer.

**Figure 3-4c. Visible, 1745Z/15 July 1981.** The photo shows extensive stratus along California coastline.

**Tropical Storms.** Tropical storms are found frequently on satellite photos south of Baja, California (Figure 3-5). They form off the western coast of Mexico and Central America. System movement is generally towards the west or northwest dissipating as they move across the vast expanse of the cooler Pacific waters. Tropical storms make their first appearance in the eastern Pacific during June (Figure 3-6). The frequency varies from 0 to 3 and averages between 1 and 2. These tropical storms reach their maximum intensity and number in August with an average of 4 to 5. July and August tropical storm tracks are shown in Figures 3-7 and 3-8.

**Figure 3-5. Visible, 2000Z/10 Aug 1999.** The figure shows multiple tropical storms south of Baja, Calif.

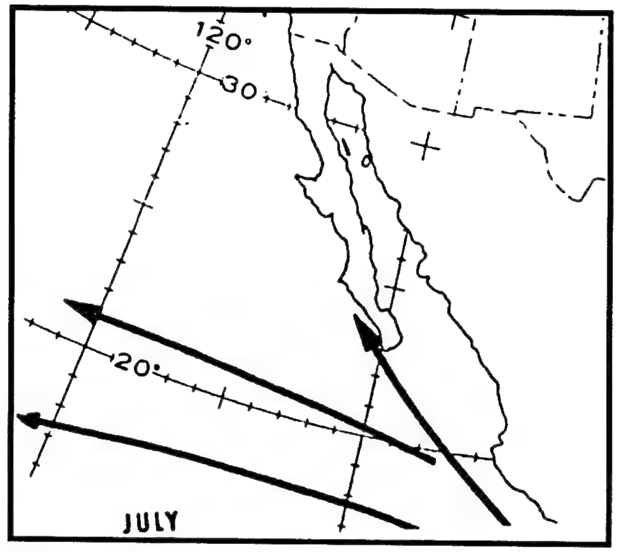


**Figure 3-7. July Tropical Storm Tracks.** The trend shows a westerly to northwesterly movement.

**Figure 3-6. Visible, 0000Z/25 June 1998.** Hurricane south of Baja, California.

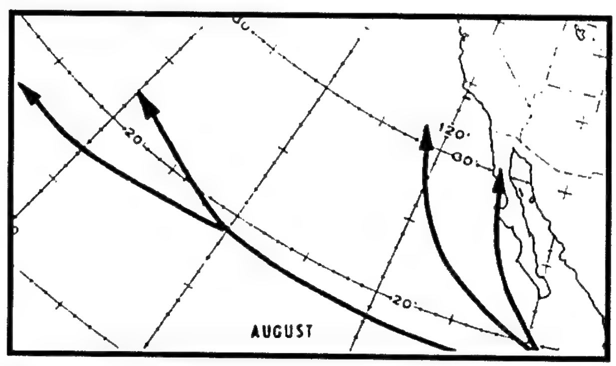


**Figure 3-8. August Tropical Storm Tracks.** The trend shows possible curvature northward later in the hurricane season.

Occasionally, however, tropical storms will move northward to affect Baja, California, northern Mexico and the southwest CONUS; they are more likely to drift northward during August and September as the subtropical ridge, located over land, weakens and shifts southward. Consequently, increased moisture and instability associated with these systems usually produce heavy thunderstorms and flash floods over the southwestern deserts. The mid-August visible photo, Figure 3-9, shows a tropical storm off the west coast of central Baja; moisture from this storm can be seen over southern California and Arizona. The effects of these tropical systems may even be felt over the southern Rocky Mountains and eastward into the Great Plains; the associated cloud systems can be easily tracked on satellite photos.

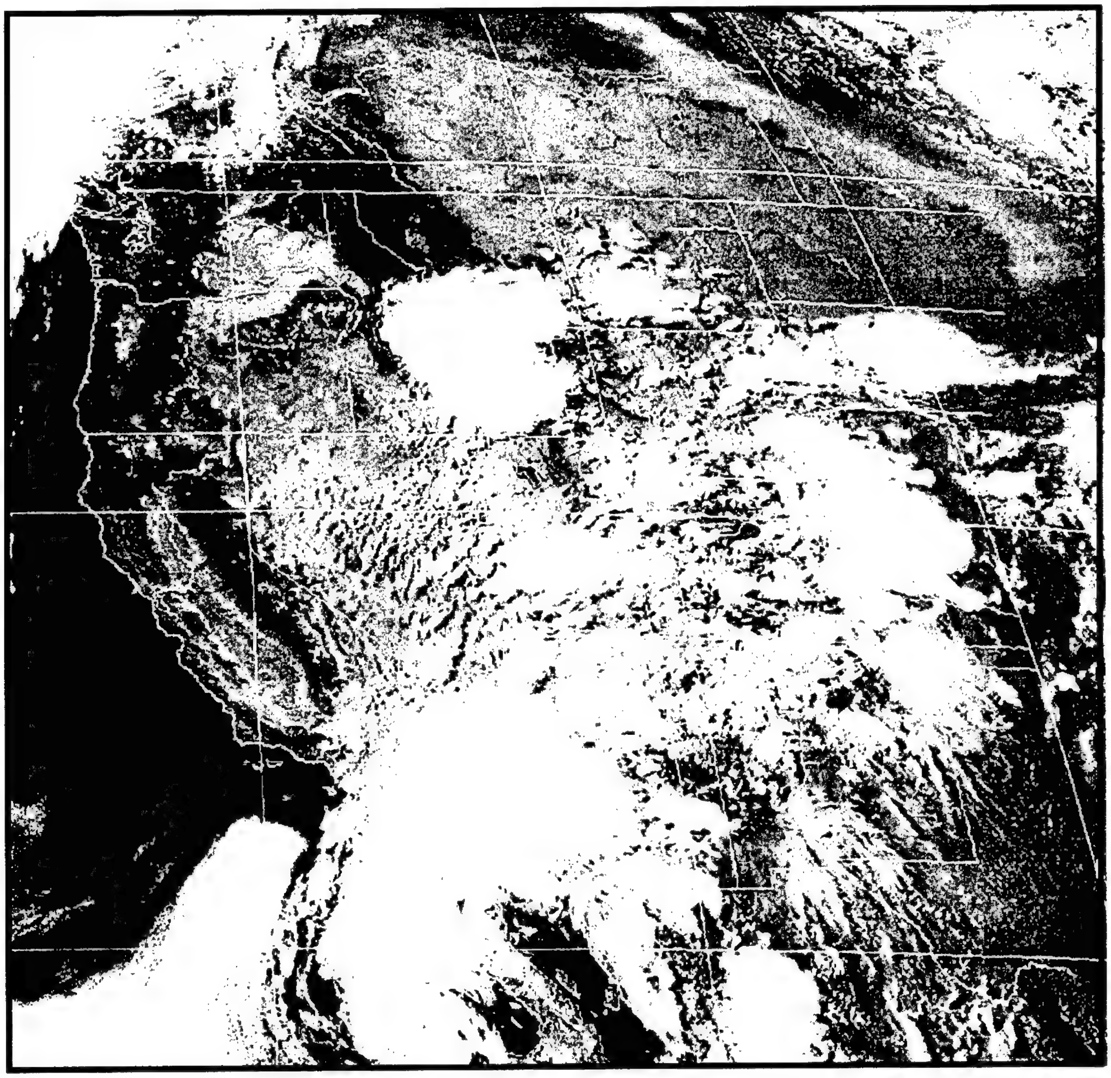

**Figure 3-9. Visible, 0000Z/10 Aug 1998.** Tropical storm off west coast of central Baja.

**Southwest Monsoon Season.** Let's focus in on one annual summer event that occurs over the western CONUS, popularly known as the Arizona Monsoon Season (see Figure 3-10; another example was shown earlier in Figure 3-3). This season usually begins over the southwestern CONUS in late June or early July when the subtropical high is positioned over the central Great Plains (Figure 3-11). Mid-level southerly winds on the backside of the ridge advect subtropical moisture northward as convection increases over the mountains of northern Mexico (Figure 3-12). The 700-mb Height/ Relative Humidity chart shown in Figure 3-12 depicts 70 percent or greater humidity. The pattern continues through the summer. The change to the monsoon season is characterized by a change from hot, dry continental air to surges of hot, moist maritime tropical air. Initially, moisture advection over southern Arizona and New Mexico occurs within the mid levels from thunderstorms that occur in surrounding regions. Low-level moisture increases gradually day to day as moisture is added from thunderstorm outflows. Gulf of California moisture is also added as low-level southerly winds advect moisture into southern Arizona. If the Bermuda Ridge is pronounced it will extend westward into western Texas and eastern New Mexico (Figure 3-13). Gulf moisture will spread westward to provide moisture for thunderstorm development over the New Mexico mountains. Gulf moisture may continue westward through the New Mexico mountain passes to southern Arizona.

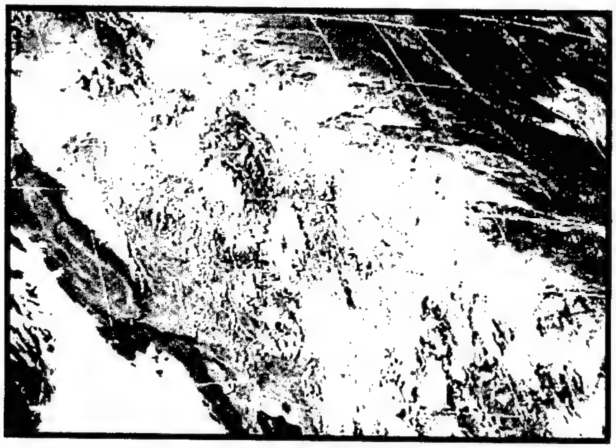

**Figure 3-10. Visible, 0000Z/05 Aug 1999.** Extensive monsoon moisture over the western CONUS.

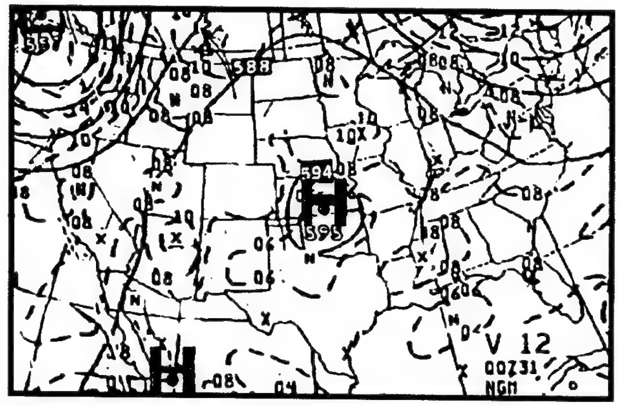


**Figure 3-11. 12-Hour, 500-mb Heights/Vorticity, 0000Z/31 August 1987.** Subtropical high over central Great Plains.

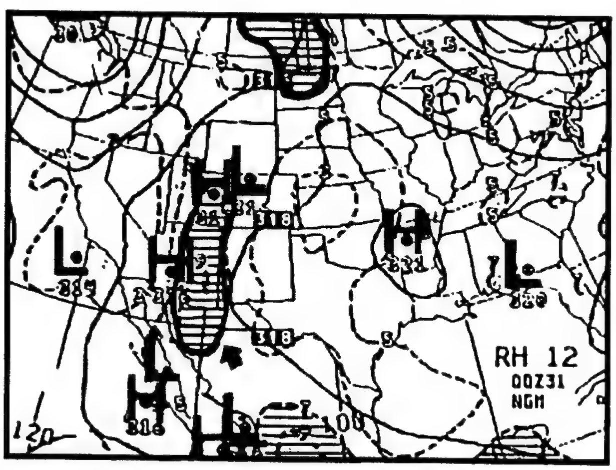


**Figure 3-12. 700-mb Height/Relative Humidity 0000Z/31 August 1987.** Moisture axis shown over Arizona and Utah.

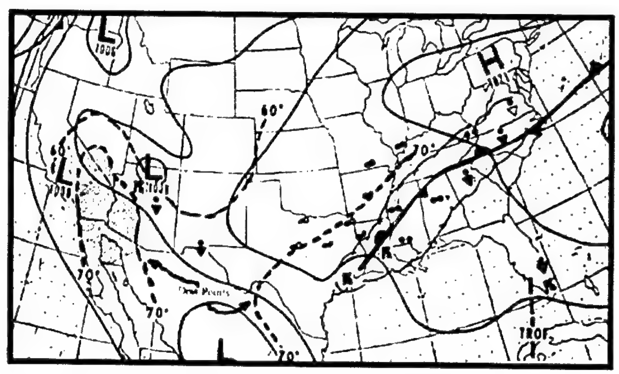

**Figure 3-13. Surface Analysis, 0000Z/21 July 1979.** Bermuda Ridge extends westward.

Figure 3-14a through 3-14h depict the onset of a monsoon season several years ago which began in mid-June. Morning and afternoon visible photos are shown for a three-day period. In Figure 3-14a, convection is shown over Mexico and the Texas Big Bend area. The following morning, Figure 3-14b, no convection is shown, but by late afternoon thunderstorms have developed over the Sierra Madre Occidental mountains of northern Mexico to the Big Bend area (Figure 3-14c).

The diurnal cycle is repeated for the next two days as shown in Figures 3-14d through 3-14g. In Figure 3-14g, the monsoon convection has spread northward into southern Utah and Colorado where it interacted with an east-west maritime Polar stationary front.

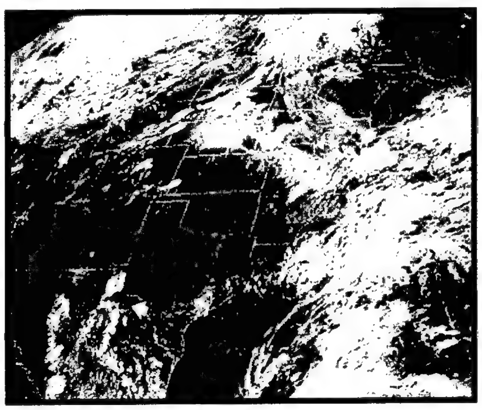

**Figure 3-14a. Visible, 2230Z/19 June 1983.** Day 1, Afternoon.

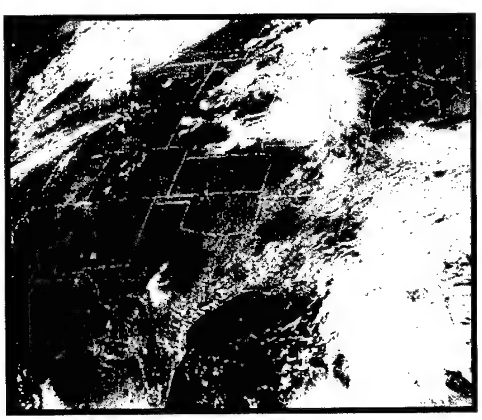

**Figure 3-14b. Visible, 1630Z/20 June 1983.** Day 2, Morning.

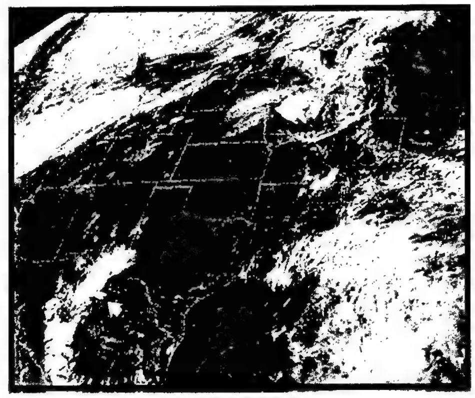

**Figure 3-14c. Visible, 2230Z/20 June 1983.** Day 2, Afternoon.

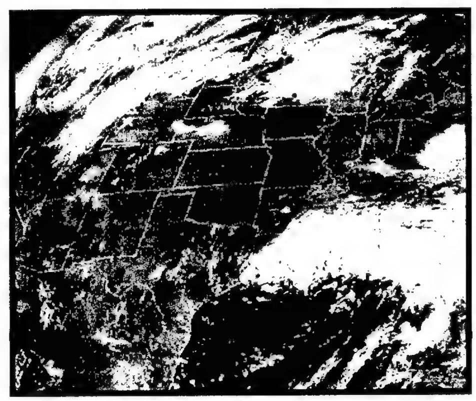

**Figure 3-14d. Visible, 1530Z/21 June 1983.** Day 3, Morning.

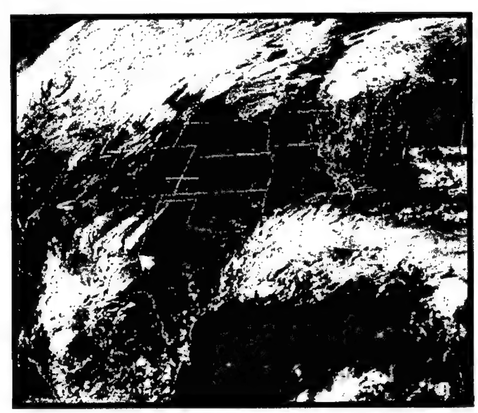

**Figure 3-14e. Visible, 2231Z/21 June 1983.** Day 3, Afternoon.

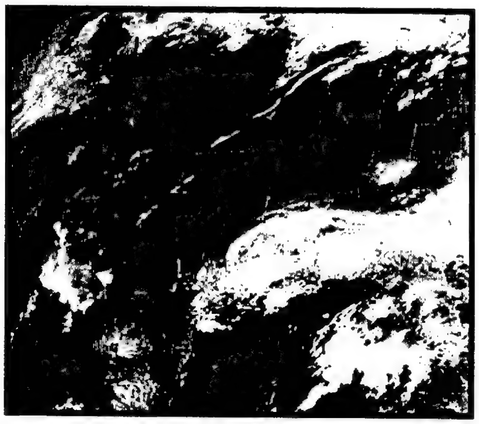

**Figure 3-14f. Visible, 1530Z/22 June 1983.** Day 4, Morning.

**Figure 3-14g. Visible, 2231Z/22 June 1983.** Day 4, Afternoon.

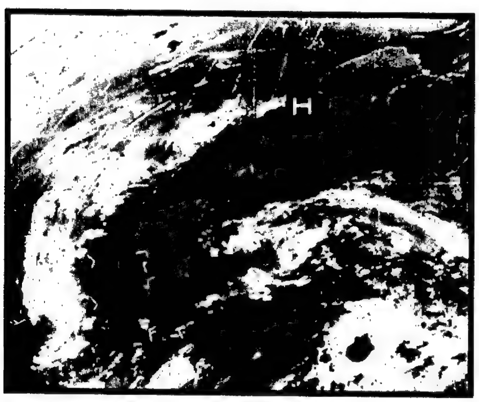

**Figure 3-14h. Infrared, 1100Z/23 June 1983.** Monsoonal moisture can be seen from Mexico to the central Rocky Mountains. The moisture has become deep enough to sustain convection and rain showers through the early morning hours.

The related 500-mb analysis (Figure 3-15) shows a light southeasterly flow over northern Mexico, Arizona and New Mexico. Figure 3-16 depicts the surface conditions.

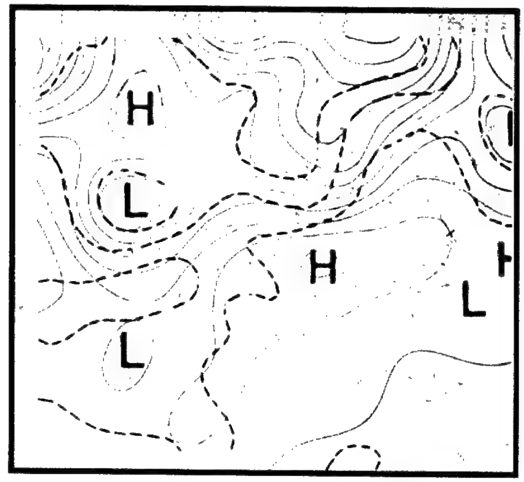

**Figure 3-15. 500-mb Analysis, 1200Z/23 June 1983.** Light southerly flow over the southwest CONUS

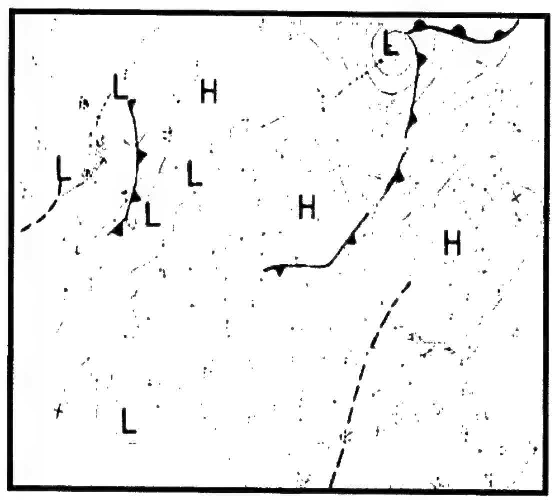

**Figure 3-16. Surface Chart, 1200Z/23 June 1983.** The figure shows the southwestern surface low.

A breeding ground for daily afternoon convection during the monsoon is the Mogollon Rim of central Arizona (noted by the arrows in Figure 3-17). Often, a shallow high-pressure center is shown over the cooler mountains of northern Arizona. These thunderstorms generally stay along the rim. However, when the air mass in the lower elevations south and southwest of the rim is very moist and unstable (dew points in the high 60's and 70's) then rim thunderstorms may drift southward off the cooler

mountains to feed on this moist and unstable air mass. Isolated severe thunderstorms may occur as the storms move from the mountains into the lower elevations, especially if there is a mid-level northerly to easterly wind component. In Figure 3-18, an area of strong convection (noted by the arrow) is shown over the eastern Arizona mountains. Strong outflow winds were occurring in the Tucson/Davis-Monthan area at the time of this photo (Tucson 2300Z observation: gusts to 58 knots). Many wind damage reports were received. The Phoenix area was hit by strong winds four hours later. In this example, the steering winds were not easterly; however, the locations mentioned above were still affected by mountain thunderstorms.

An infrequent subtropical high location during summer is shown in Figure 3-19 over the central areas of the western CONUS. The middle- and upper-wind flow would be from the northeast and/or east across Arizona and western New Mexico as shown in Figure 3-19. Locations west of the eastern Arizona mountain ranges (Tucson, Davis-Monthan AFB and Phoenix) should be aware that thunderstorms may move off these mountains by late afternoon or early evening when the steering flow is easterly. Severe thunderstorms may occur (mainly strong surface winds) as cool mountain air rushes downhill into a warmer, more unstable air mass. An easterly cyclonic wind flow across the eastern

**Figure 3-17. Visible, 2300Z/17 July 1998.** Thunderstorm development along the Mogollon Rim.

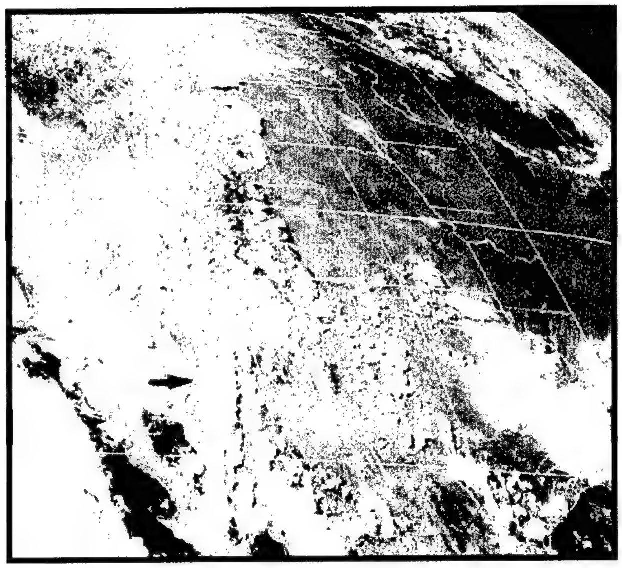

**Figure 3-18. Visible, 2330Z/7 July 1999.** Strong thunderstorms over eastern Arizona

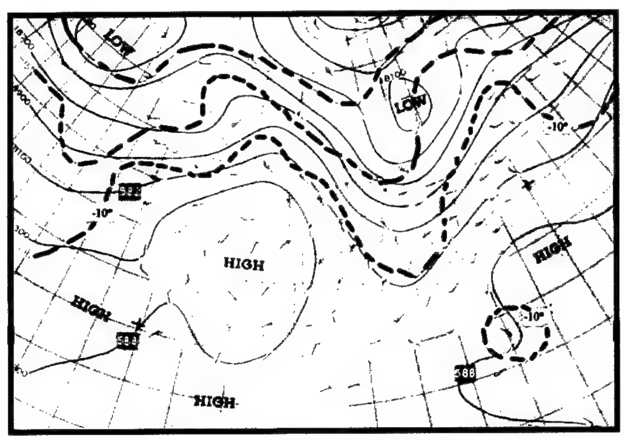


**Figure 3-19. 500-mb Analysis.** Subtropical high over the western CONUS.

Arizona Mountains would also occur when an upper low appears over northwestern Mexico.

The upper high's location shown in Figure 3-19 would most likely suppress and shift the monsoon moisture fields southward due to a change in the mid-level wind flow from southerly to a westerly direction topside of the high. On the other hand, locations over Nevada and California would see an increase in thunderstorm activity as monsoon moisture spreads northward on the western side of the subtropical high.

As one can see, the monsoon season produces a considerable number of daily orographic thunderstorms by mid-afternoon. Thunderstorm intensity is generally in the "garden variety" range (=35 knots/½ inch hail); however, moderate thunderstorms (mostly gusty surface winds) may occur especially at locations near mountain ranges. If there is mid-level cooling to steepen lapse rates, then isolated severe thunderstorms may develop anywhere within the monsoon moisture belt, generally by late afternoon or early evening in favorable orographic areas. In Figure 3-20, many convective cells are shown and to pinpoint any potential severe thunderstorm cells using visible satellite pictures is a challenge. Collapsing tops may be determined from IR photos and Doppler radar if you are lucky enough to catch it among the numerous surrounding convective cells. Additionally, flash floods are not uncommon due to stationary or slow-moving mountain thunderstorms.

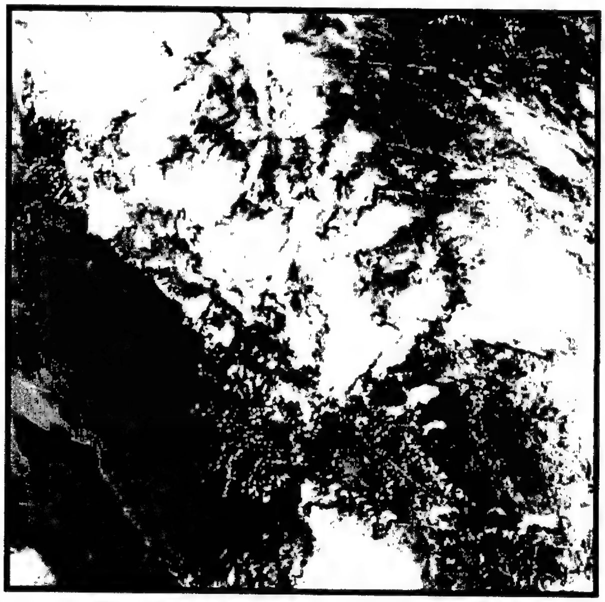

**Figure 3-20. Visible, 2346Z/21 June 1999.** The figure shows southwest monsoon thunderstorms.

Organized areas of severe thunderstorms associated with short waves (usually small-scale) are likely as the associated PVA and cooling moves over moist and unstable mountainous terrain. Organized severe convection occurs more often over eastern Oregon/ Washington (leeside trough development east of the Cascades) eastward across Idaho and Montana; these events are associated with short waves and mP cold fronts moving eastward topside of the subtropical high.

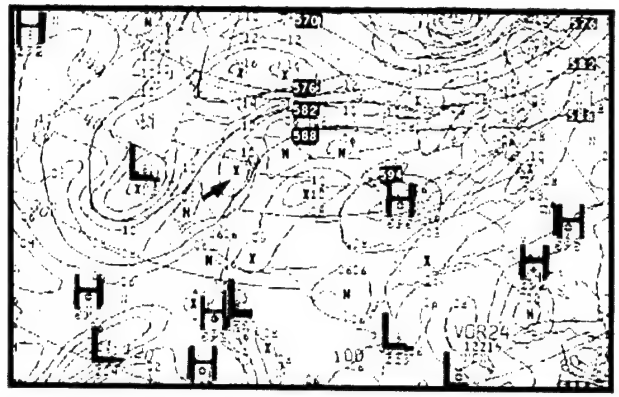

**Figure 3-21. NGM 24-Hour Forecast, 1200Z/19 July 1999.** The arrow points out a PVA Lobe Utah/Nevada.

Major troughs persist over the cooler Pacific Ocean areas throughout the summer. Occasionally, troughs move inland into western California, Oregon and Washington as the subtropical high shifts eastward. Short waves (and PVA) eject from these troughs and move northeastward across the Great Basin to the northern Rockies (Figure 3-21). In Figure 3-21, a small PVA lobe within southwest flow is shown by the arrow over the Nevada/Utah area. Afternoon severe thunderstorms may occur when these short waves move over the monsoon moisture field, located along and east of the Sierra Nevada mountain range.

A common summertime event is shown in Figure 3-22. Thunderstorms develop over the Sierra Nevada and Cascade mountain ranges and stay on the mountains through their life cycles (noted by the arrows). The Sacramento and San Joaquin Valleys generally remain

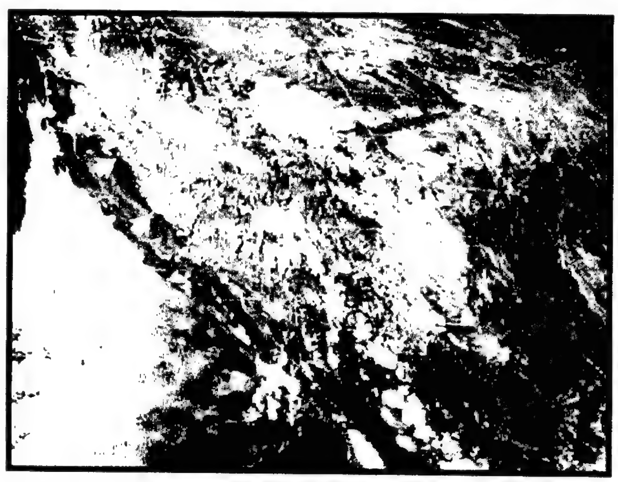

**Figure 3-22. Visible, 2345Z/31 July 1984.** Thunderstorms develop over the Sierra Nevada and Cascades.

free of convection. Valley stations will report cumulonimbus and lightning over these mountains. Stratus appears daily along the California coast as shown in the photo.

A strong fetch of warm, monsoonal moisture from the subtropics is often very moist from the surface to the midlevel (wet bulb zeros are at higher levels); these conditions are not conducive for producing an outbreak of severe convective weather. On the other hand, forecasters located on the fringes of a moist layer, or in areas where dew points are low and strong surface heating is expected, should look for inverted Vs on their morning (or forecast) RAOB. Inverted V soundings warn forecasters of the likelihood of strong convective winds by late afternoon or in to the early evening hours.

Forecasters should monitor the water vapor for the location and areal extent of the monsoon flow. The moisture plume often shifts east or west or may shrink southward due to the movements of the subtropical ridge and/or an approaching pacific trough. The moisture plume is very noticeable on water vapor pictures and loops. One must be on the lookout for embedded, short waves traveling northeasterly within the moisture plume which may trigger small areas of moderate or severe thunderstorms. Figure 3-23 below illustrates monsoonal moisture as noted by the arrows. Thunderstorms have developed within the plume over Mexico, New Mexico and southeastern Colorado as indicated by the brighter areas.

**Figure 3-23. GOES West Water Vapor, 2330Z/6 July, 2000.** The arrows point out a moisture plume over the southwest CONUS.

Monsoon thunderstorms are generally diurnal with most activity ending by early evening unless sustained by a front or an upper air disturbance. Thunderstorms often persist through the early morning hours over the mountain areas of southern Arizona and northern Mexico where deeper moisture continues (Figure 3-24).

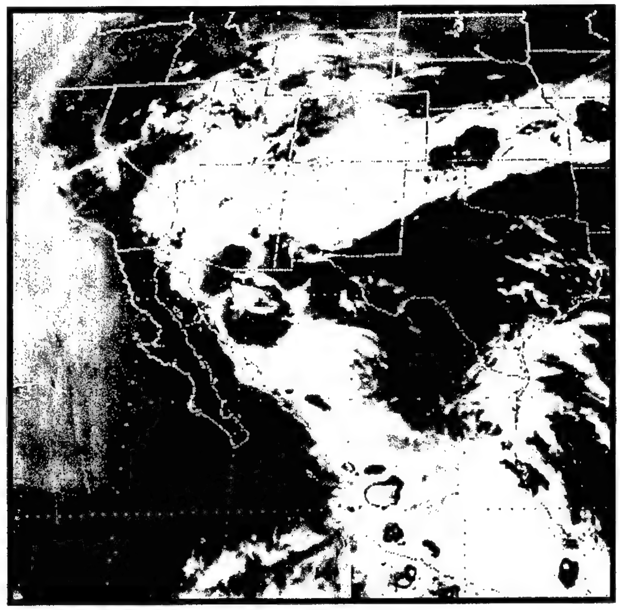

**Figure 3-24. Infrared, 0550Z/15 July 1985.** Late evening monsoon thunderstorms persist over southern Arizona and northern Mexico. Monsoon moisture has spread eastward across the central Great Plains.

*Summer Regimes*

**Chapter 4**

# Central CONUS

**General.** The following discussion covers the area from the Rocky Mountains to the Mississippi River. Most of the discussion deals with the presence of the subtropical high and its associated weather. Also, nocturnal thunderstorms occur often across the central CONUS while daytime air mass thunderstorms prevail over the southeastern and southern CONUS. Considerable discussion regarding nocturnal thunderstorm activity will be presented.

**Subtropical High - Central CONUS.** During the summer months a favorite location for the subtropical ridge and high center to settle over is in the central areas of the Midwest as depicted in Figure 4-1 (shown earlier in the model; Figure 2-8). When this regime occurs, short waves and their associated frontal systems track around the periphery of the high and will be shown and discussed in the following paragraphs.

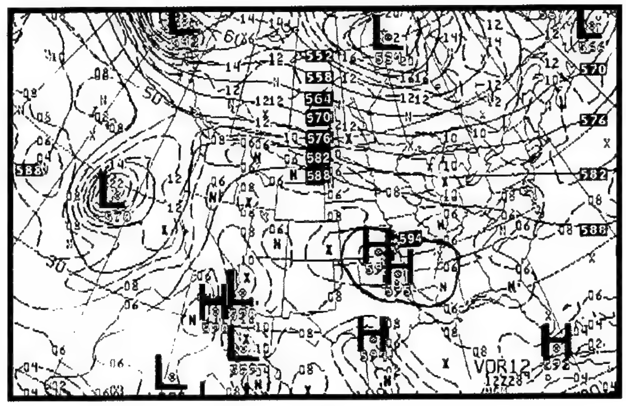

**Figure 4-1. NGM Heights/Vorticity, 12-Hour, 28 July 1999.** Subtropical high - Central CONUS.

As a reminder from previous discussions, the polar jet settles in its summer position over Canada; low-pressure systems move across Canada and/or the northern CONUS. This is the severe thunderstorm season for the northern CONUS, from eastern Washington/Oregon to the East Coast. The most active severe thunderstorm area (associated with fronts) begins along the Montana and Wyoming Rocky Mountains where fronts stretch eastward across the Dakotas and Great Lakes to the northeastern CONUS (Figure 4-2) and interact with moist and unstable air masses to the south.

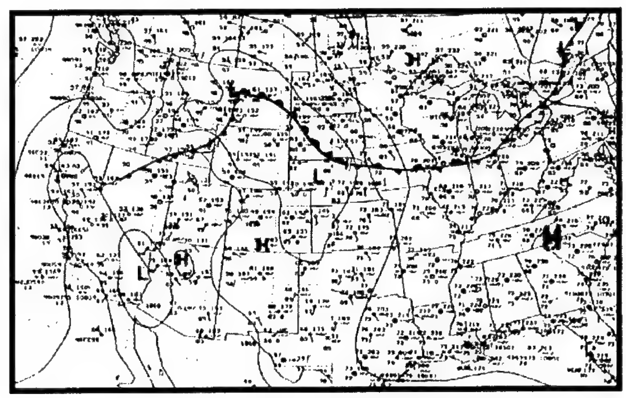

**Figure 4-2. Surface, 1200Z/18 July 1999.** East-west frontal system across the northern CONUS.

**North-South Stationary Fronts or Surface Troughs.** Northern Great Plains forecasters should always be aware of severe thunderstorm outbreaks that can produce tornadoes when a frontal low moves into existing moisture and thermal axes such as shown in Figure 4-3. In this event, the upper wind flow was from the west to northwest.

A minor short wave moved across North Dakota during the day (Figure 4-4 on next page). Fifty-eight severe thunderstorms including 12 tornadoes were reported between 2100Z and 0600Z over North Dakota and northwest Minnesota (tornadoes were reported near Minot and Grand Forks AFBs).

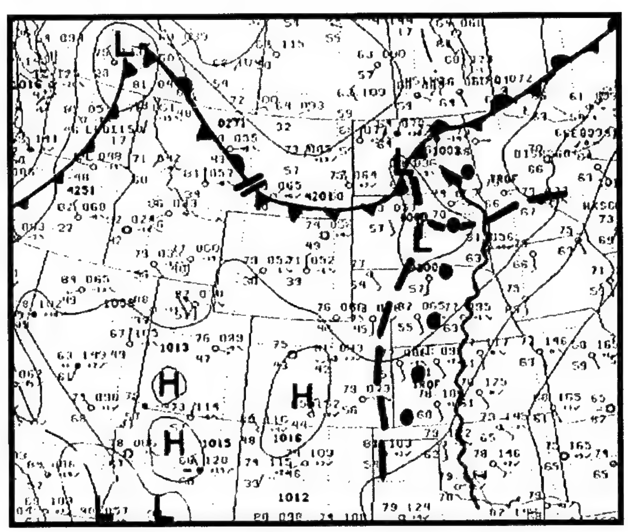

**Figure 4-3. Surface Analysis, 0300Z/14 Jul 1999.** Severe thunderstorm outbreak North Dakota/Minnesota.

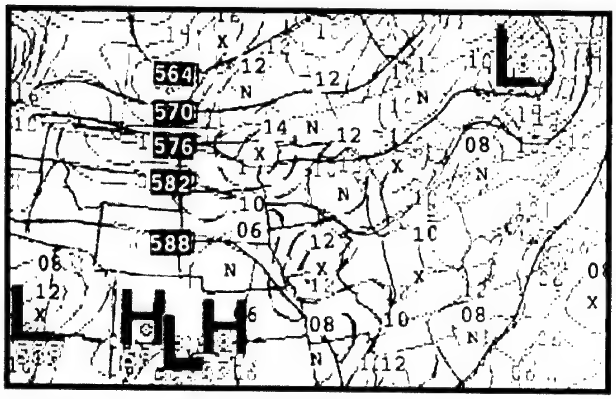


**Figure 4-4. NGM 00-Hour Heights/Vorticity, 0000Z/14 July 1999.** A short wave moved across North Dakota/Minnesota.

Locations east of the Mississippi River will experience more cold frontal passages within north-west flow on the front side of the central Great Plains subtropical high. Conversely, when upper level southwest flow occurs west of the subtropical high, then pacific mP cold fronts crossing the northern and central Rocky Mountains will often "hang up" over the western Great Plains (often within the strong surface heating of the lee-side trough). These fronts frequently aligned northeast to southwest over the northern Great Plains as they become stationary or undergo frontolysis (Figure 4-5).

Thunderstorms form along these boundaries (if not capped) and move east as squall lines during late afternoon and evening as shown in Figure 4-5. Continuity must be maintained on these old boundaries, which may be depicted as surface troughs (in conjunction with the lee-side trough) over the western Great Plains.

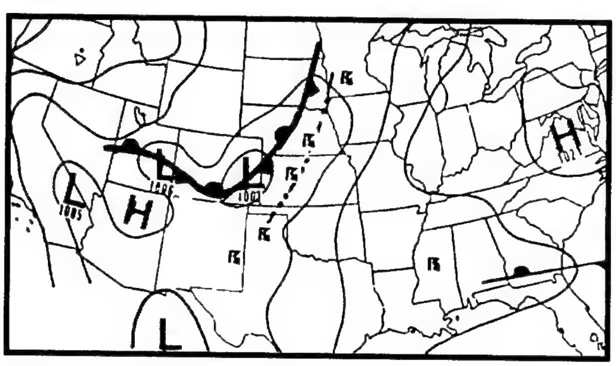

**Figure 4-5. Surface Mid-July.** The cold front is becoming stationary.

Figure 4-6 shows the subtropical ridge/high over the Mississippi Valley area. The following example shows how an extensive thunderstorm line developed along a surface trough over the western Great Plains as depicted on the surface analysis (Figure 4-7). Keep in mind that the upper level features were weak. Strong surface convergence and a moist and unstable heated air mass were in place.

The related surface chart, Figure 4-7, reveals a surface trough over western Dakotas and Nebraska and becomes aligned with the lee-side trough over eastern Colorado. The air mass over the Great Plains, east of the lee-side trough, generally is moist and unstable within southerly flow throughout the summer.

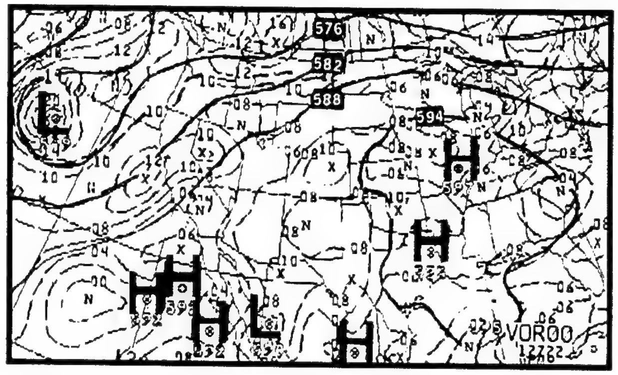


**Figure 4-6. NGM 00-Hour Heights/Vorticity, 1200Z/22 July 1999.** Subtropical high located over the Mississippi Valley area.

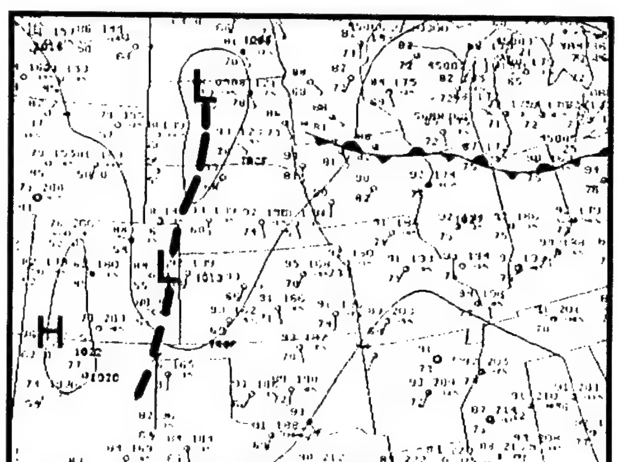

**Figure 4-7. Surface Chart, 1800Z/22 July 1999.** Surface troughs over the western Great Plains.

The late afternoon visible satellite picture, Figure 4-8 (2340Z, 22 Jul, 99), shows that a line of thunderstorms developed along the surface trough. Between 2230Z and 0600Z, fifty-six severe thunderstorms were reported from the eastern North Dakota/western Minnesota area southwestward across central South Dakota. Nine tornadoes were reported in central South Dakota. The severe thunderstorm line continued eastward into eastern Minnesota and Wisconsin throughout the remainder of the morning. As one can see in this example, surface and upper level features may be weak, yet a severe thunderstorm event can occur along a convergence zone that is moist and unstable.

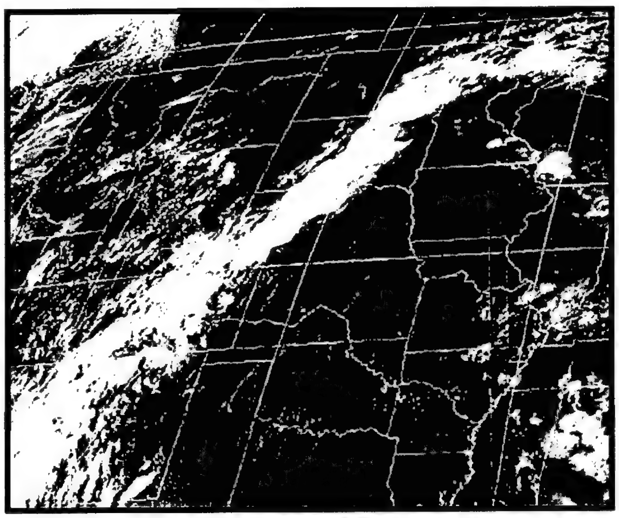

**Figure 4-8. GOES East, 2340Z/22 July 1999.** Severe thunderstorm line developed along the boundary

**East-West Stationary Fronts or Surface Troughs.** Figure 4-9 depicts another typical frontal structure during summer: maritime or continental polar cold fronts that become aligned east-west across the central and upper Midwest and eastward. The associated low system is usually located in Canada. In Figure 4-9, moist air which overruns the stationary front, generally produces extensive thunderstorm areas and heavy rain in the vicinity of the of the front. The mid-morning visible satellite picture, Figure 4-10, (not related to Figure 4-9) shows an extensive line of convection along a stationary front from the Ohio Valley to Kansas; the associated low is located in the vicinity of the Hudson Bay area. Over 70 severe thunderstorm reports were received across the boundary during the afternoon and evening. If favorable westerly mid-level winds exist then thunderstorms may drift away from the front, become squall lines by mid afternoon or early evening. In this situation, thunderstorms will continue to move southeastward along the east-west thermal axes and moisture pools.

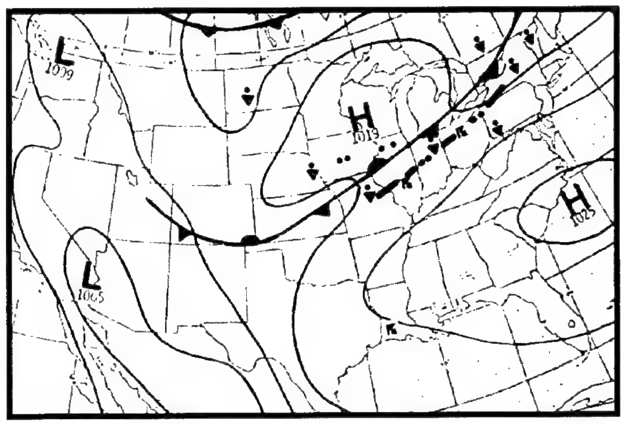

**Figure 4-9. Surface East-West Stationary Front.** Large thunderstorm areas and heavy rain is occurring.

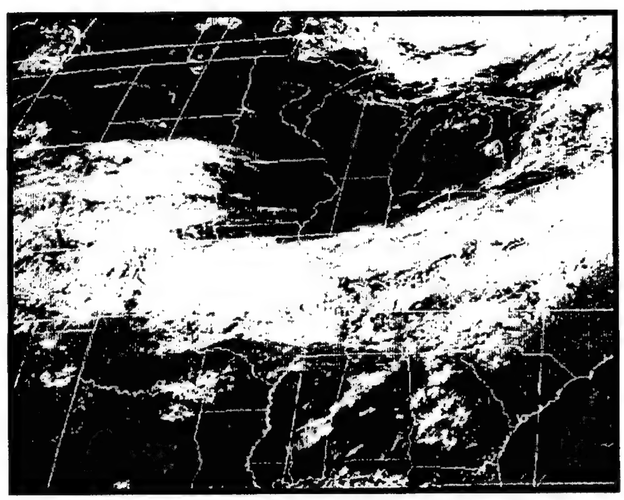

**Figure 4-10. GOES East, 1302Z/23 July 1998. Extensive line of convection central CONUS**

Another example of summer thunderstorm activity associated with a stationary or warm front is shown in Figures 4-11 through 4-13. In Figure 4-11, a warm front extends across the central CONUS. The 1200Z NGM analysis, Figure 4-12, depicts weak mid-level ridging and winds over the warm front; the subtropical high is shown over eastern Oklahoma. Little, if any, upper dynamics support the strong warm frontal thunderstorms shown in Figure 4-13. Warm frontal overrunning, convergence, surface heating and a moist and unstable air mass provided the parameters; in the mid troposphere, thunderstorm developed topside of the subtropical high (north and northeast sector) where it is likely to be more diffluent (more discussion on this feature follows later). Besides the warm moist air mass that prevails over the central CONUS, there is another source of moisture that interacts with frontal systems over the Great Plains: the advection of mid-level monsoon moisture across the Rocky Mountains as noted by the arrows shown in Figure 4-14. The subtropical high is shown over southern Missouri; monsoon moisture has advected eastward over Nebraska and northern Kansas along a stationary front.

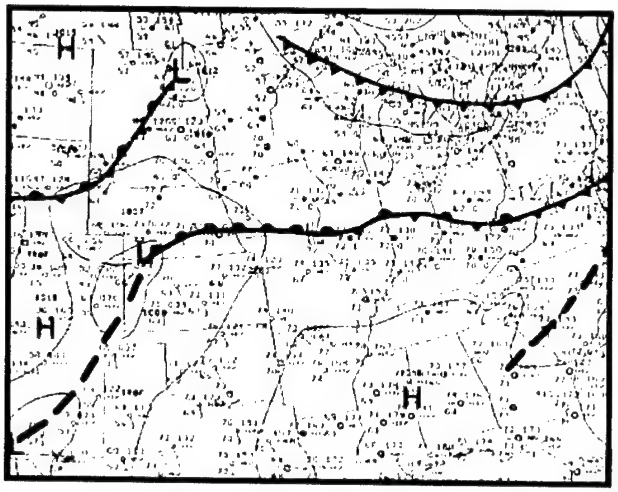

**Figure 4-11. Surface Analysis, 1200Z/5 July 2000.** Warm front stretches across central CONUS

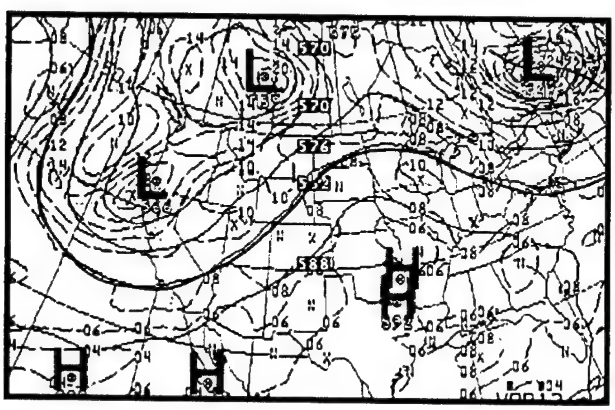

**Figure 4-12. NGM Initial Heights/Vorticity, 1200Z/ 5 July 2000.** Weak ridge over warm front.

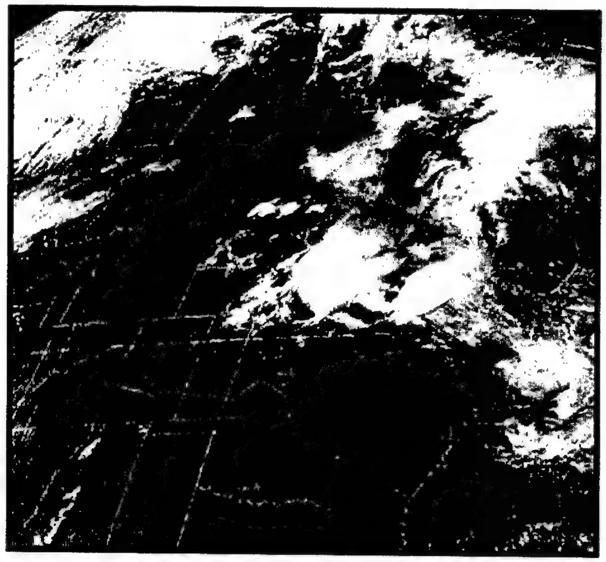

**Figure 4-13. Goes East, 1740Z/5 July 2000.** Thunderstorms cluster along and north of the warm front.

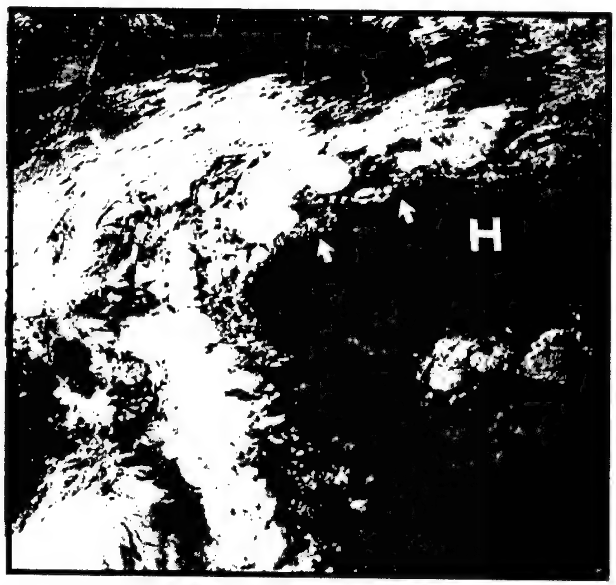


**Figure 4-14. Visible, 0000Z/19 July 1985.** Advection of monsoon moisture into the Great Plains

Another example is presented to show frontal structures and associated weather on the northern side of the subtropical ridge centered over the Central Plains (Figures 4-15 and 4-16). In Figure 4-15, a cold front appears over the northern Great Plains. The subtropical high is shown over Kansas. Thunderstorms have developed all along the front.

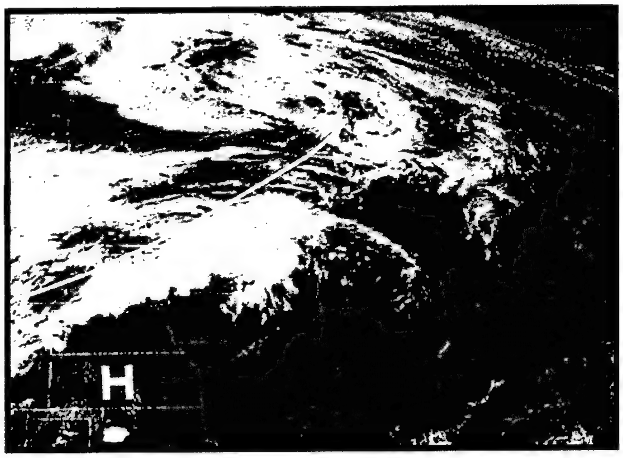


**Figure 4-15. Visible, 2310Z/17 July 1985.** The figure shows a subtropical high over Kansas. Cold frontal thunderstorms are occurring north of the high.

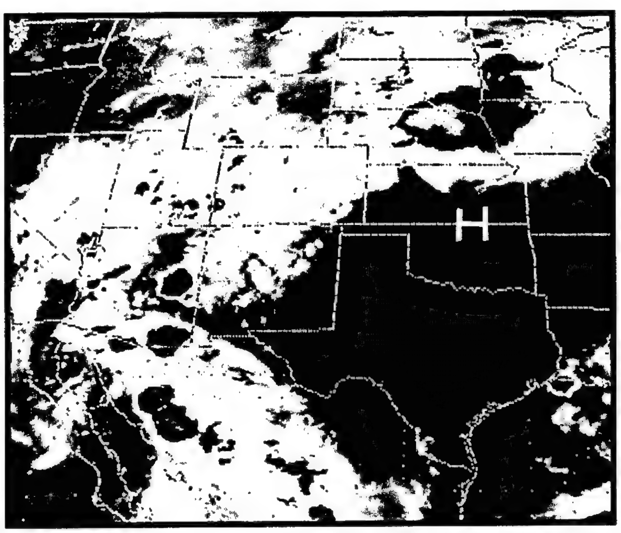


**Figure 4-16. Infrared (MB Curve), 0400Z/18 July 1985**. Thunderstorms strengthen along the stationary front monsoon moisture connection.

In many cases when northwest flow exists over the northern Great Plains, thunderstorm complexes (MCCs – discussion on MCCs will be presented later) will strengthen and persist through the early morning hours. Thunderstorms often develop and move along the northern and eastern side of the tighter temperature gradients of the subtropical high cap. The steering winds are generally from the west to northwest. As will be shown later, the 700mb +10°C temperature is generally a good guide to use to determine the southern boundary of thunderstorms over the central plains when a cap exists. Conversely, if there is strong surface heating and forcing, and a moist and unstable air mass (high CAPES) exists within the capped area then some convection will break the cap especially along the dry line over the western Great Plains.

**Mesoscale Convective Systems.** Organized, persistent areas of deep convection are visible on satellite photos during the warm season, especially over the central areas of the CONUS. These thunderstorm areas are defined as either Mesoscale Convective Systems (MCS) or Mesoscale Convective Complexes (MCCs) depending on their size. The reader should have an understanding of the difference between a MCC and a MCS since these systems occur often over the central CONUS. Abundant low-level moisture, strong instability and surface heating are the ingredients for MCC and MCS development. Definitions of MCC and MCS are (from the NOAA Glossary):

***MCC***—A large MCS, generally round or oval shaped, which normally reaches peak intensity at night. The formal definition includes minimum criteria for size, duration and eccentricity (i.e. "roundness"), based on the cloud shield as seen on infrared satellite photographs:

Size: Area of cloud tops –32 degrees C or less: 100,000 square kilometers or more (slightly smaller than the state of Ohio) and area of cloud tops –52 degrees C or less: 50,000 square kilometers or more.

Duration: Size criteria must be met for at least 6 hours.

Eccentricity: Minor/major axis at least 0.7.

MCCs typically form during the afternoon and evening as individual thunderstorms during which time the potential for severe weather is greatest. During peak intensity (nocturnal period), the primary threat shifts toward heavy rain and flooding.

***MCS***—A complex of thunderstorms that become organized on a scale larger than the individual thunderstorms, and normally persists for several hours

or more. MCSs may be round or linear in shape, and include systems such as tropical cyclones, squall lines and MCC (among others). MCS often describes a cluster of thunderstorms that does not satisfy the size, shape, or duration of an MCC.

MCCs/MCSs generally move along the northern and eastern periphery of the subtropical high where it is more likely to be diffluent in the upper levels (generally northwest flow). Mesoscale convective systems/complexes usually begin as a group of cells forming within a moist, unstable zone during the afternoon hours. The triggers, besides surface heating, will be low-level convergence, dry lines, fronts and the upslope along Rocky Mountains. Let's look at an MCC event:

The IR photos, Figures 4-17 and 4-18, depict a Rocky Mountain event. In Figure 4-17, thunderstorm cells have developed within the monsoon moisture field over the Rocky Mountains (noted by the arrows). The subtropical high is located over western Oklahoma. Thunderstorms continue to grow and merge (while going through their life cycles). Large amounts of moisture are transported into the upper levels by these cells, and eventually combine to produce an apparent single monster as noted by the arrow in Figure 4-18.

These systems continue to grow throughout the night times hours producing numerous thunderstorms and heavy rainfall over a given area. They are often slow moving due to light steering winds. They initially may be the result of severe thunderstorms with tornadoes and hail during the heating hours, but this type of weather rarely persists once the nocturnal MCC has developed. Gusty surface winds <50 knots and small hail may occur. Many mature systems often reveal strong cirrus outflows that indicate the divergent area aloft (Figures 4-19 and

**Figure 4-17. Infrared (MB), 2300Z/12 July 1981.** Thunderstorm cells have organized over Colorado

**Figure 4-18. Infrared (MB), 0600Z/13 July 1981.** MCC continues to strengthen over western Nebraska and South Dakota..

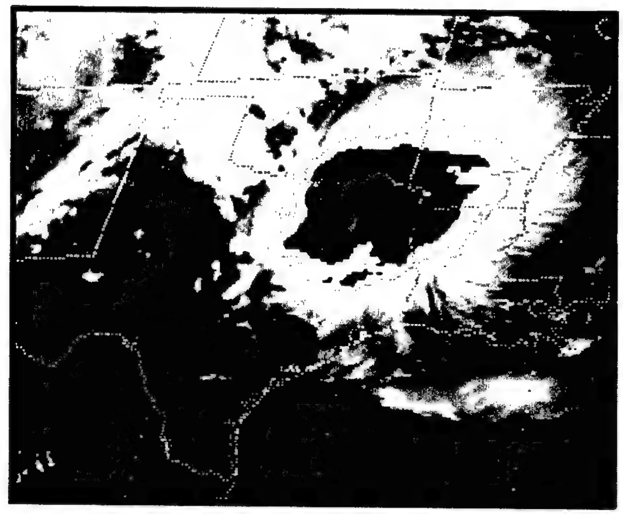

**Figure 4-19. Infrared (MB), 1300Z/27 May 1981.** Developed MCC over the southern Great Plains.

4-20). The IR photos shown (MB enhancement curves) easily identifies most mature systems. The maximum tops in these MB photos often appear within the white scale and reveals very high tops (Figure 4-20).

Mesoscale convective complexes that persist through the morning hours appear in visible pictures as circular areas with cirrus outflows in all directions. An example is shown in Figure 4-21 over eastern Missouri and eastward into the Ohio Valley area (indicated by the arrow; this MCC began over Nebraska and Iowa 12 hours earlier). Visible pictures do not help much, you should monitor IR photos particularly the MB curve, for continuity on cloud top heights to see if the system is intensifying or dissipating. These systems often have identifiable outflows associated with them – forecasters should look for redevelopment of thunderstorms along these outflows.

Mesoscale convective systems/complexes may move southward on the east side of the subtropical high (usually across the Missouri Valley area)) as shown in Figures 4-22 and 4-23. There are several cases where convective systems have developed over the central plains and moved to the Louisiana/Mississippi gulf coast. Figures 4-22 and 4-23 depict a MCC that had moved from northwestern Missouri to northern Arkansas in approximately eight hours. Notice the cirrus outflows in Figure 4-23.

The following northwest flow regime produced a series of Mesoscale Convective Systems associated with PVA that track southeastward across the Great Plains. Each event produces severe thunderstorms through the afternoon and into the early morning hours. There is usually enough time between each MCS passage for the surface and lower levels to return to unstable environment. These events generally begin over the


**Figure 4-20. Infrared (MB), 1500Z 22 June 1981.** Developed MCC over the central Great Plains.

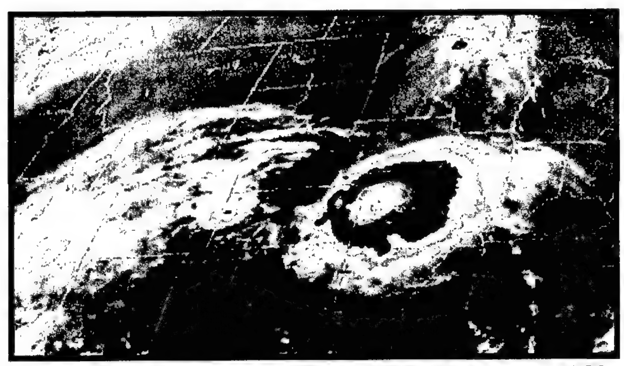

**Figure 4-22. Infrared (MB), 0800Z /13 August 1982.** MCC over eastern Kansas and Missouri.

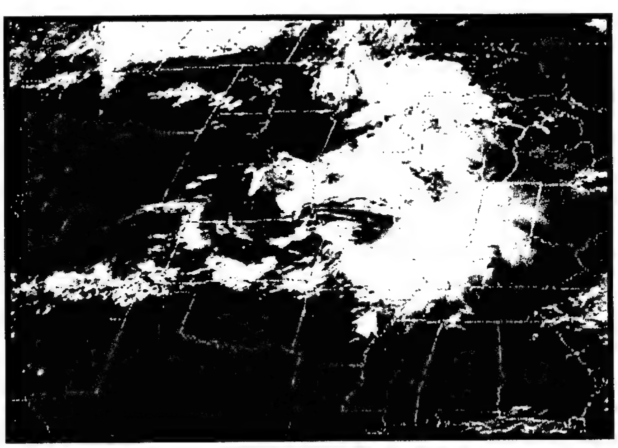

**Figure 4-21. Visible, 1530Z/23 July 1981.** Morning picture of MCC over Ohio Valley.

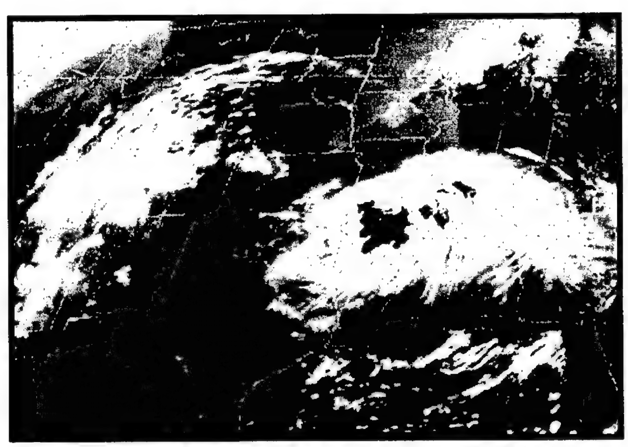

**Figure 4-23. Infrared (MB), 1500Z/13 August 1982.** Seven hours later from Figure 4-22.

western Great Plains and the Rocky Mountains where orographic lift, dry line convergence and/or stationary frontal boundaries initiate convection. The upper flow is northwesterly and diffluent; the subtropical high is generally located across the southern Great Plains and Rocky Mountains. Several occurrences will be shown.

The first mesoscale thunderstorm system that produced a severe thunderstorm event is shown on the 00Z ETA analysis, Figure 4-24, over the Tennessee and Alabama area. No satellite or analysis data was captured for the beginning of this event. The afternoon visible image, Figure 4-25 shows the MCS over Tennessee/Alabama and is its configuration matches the PVA lobe shown in Figure 4-24. The severe thunderstorm report summary

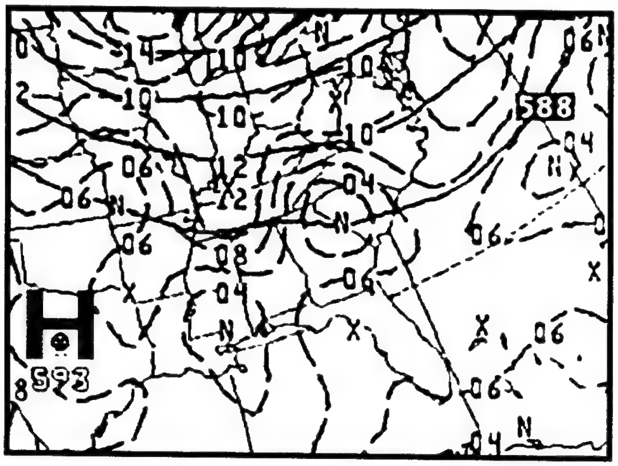

**Figure 4-24. ETA Analysis, 0000Z/21 July 2000.** PVA Lobe over Tennessee and Alabama.

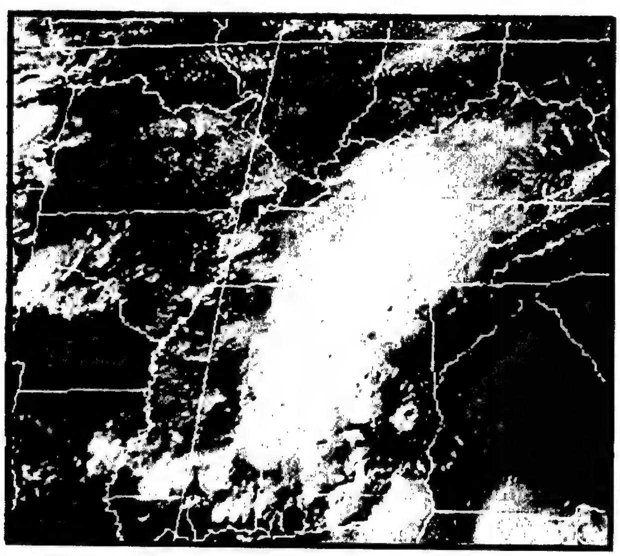

**Figure 4-25. GOES 2315Z/20 July 2000.** Satellite confirms PVA Lobe.

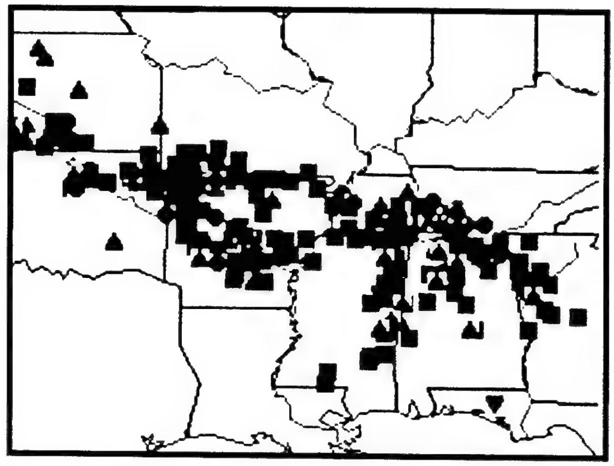

**Figure 4-26. Severe Thunderstorm Reports 20/1000Z – 21/0600Z.** Most reports are wind damage from Arkansas to Alabama

(20/1000Z to 21/0600Z), Figure 4-26, depicts the severe activity with this MCS as it tracks across eastern Kansas and Oklahoma, Arkansas into Tennessee and Alabama. The severe event began over eastern Kansas and Oklahoma during mid afternoon. Most severe reports were strong convective gusts and wind damage as shown in Figure 4-26 (Symbology is shown in Figure 4-35). The event suggests a Derecho (straight-line convective wind damage) may have occurred.

The second MCS event developed over the western Great Plains during the afternoon (within 24 hours of the first event just shown). This system evolved into a MCC during the evening hours. A PVA lobe emerged from the Rocky Mountains and strengthened over the central Great Plains within 12 hours (Figures 4-27 and

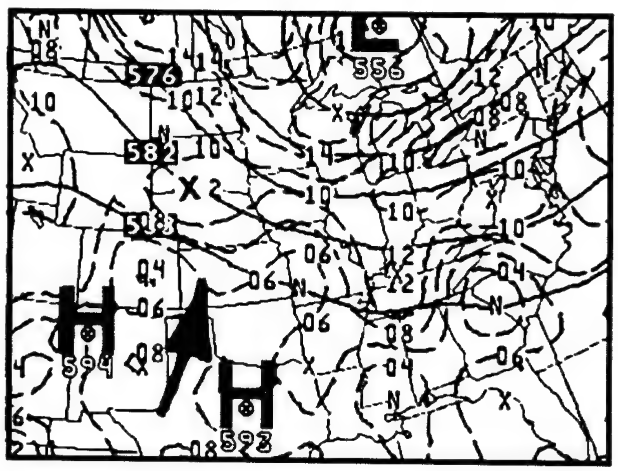

**Figure 4-27. ETA 500-mb Heights/Vorticity Analysis, 0000Z/21 July 2000.** The arrow points to strengthening PVA in northwest flow

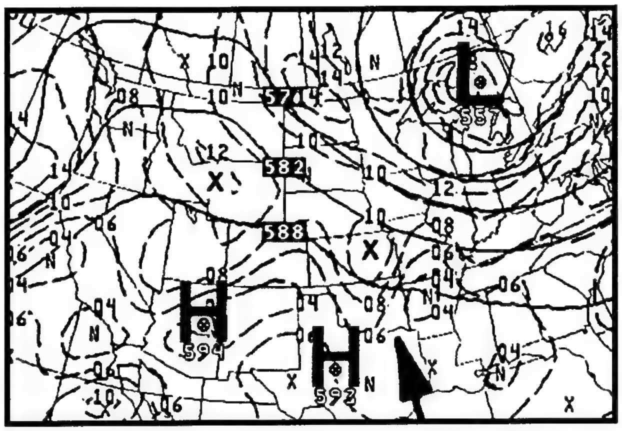

**Figure 4-28. ETA 12-Hour Forecast 500-mb Heights/ Vorticity, 1200Z/21 July 2000.** PVA continues to strengthen

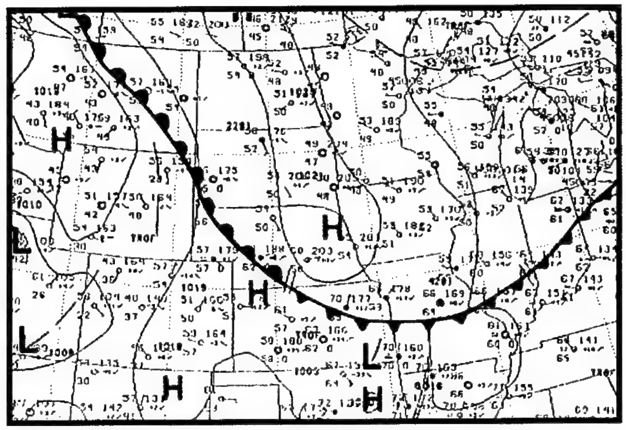

**Figure 4-30. Surface Analysis, 1200Z/21 July 2000.** Cold front becoming stationary over Missouri and Kansas.

4-28); noted by the arrows). The central Great Plains was under midlevel northwest flow as the subtropical high was located over the southwestern CONUS. The PVA moved southeastward into Arkansas within 24 hours. The 0000Z 500-mb and surface analyses the following morning are shown in Figures 4-29 and 4-30; they are included to show conditions prior to and during late afternoon MCS development over the western Great Plains. At the 500-mb level, Figure 4-29, the Great Plains is under northwest flow. The analyzed contours would not indicate that a short wave exists where the developing vorticity is located. A weak thermal trough indicates cold air advection (Figure 4-29). In Figure 4-30, 12 hours later, a cold front extends from Illinois to eastern Kansas becoming stationary to the mountains (surface chart for 21/0000Z was not available).

The following selected satellite sequence illustrates MCS (MCC) formation and development associated with the vorticity shown in Figures 4-27 and 4-28. In the late afternoon visible image, Figure 4-31, a line of Rocky Mountain thunderstorms had moved into the eastern Wyoming and Colorado and the western Great Plains. Another area of thunderstorms developed along the stationary front (shown earlier in Figure 4-30) over southern Nebraska and eastern Kansas and Oklahoma. Severe thunderstorms, mostly convective gusts and hail, occurred over eastern Colorado, Wyoming and Kansas during the afternoon formative period.

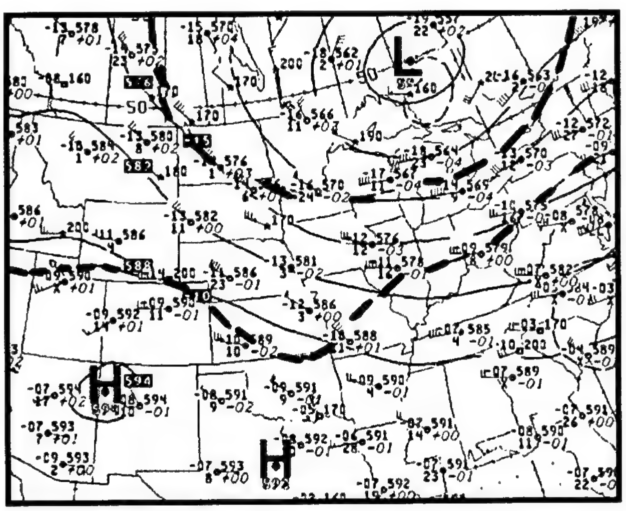

**Figure 4-29. 500-mb Analysis, 0000Z /21 July 2000.** Northwest flow prevails; thermal trough over the central Plains.

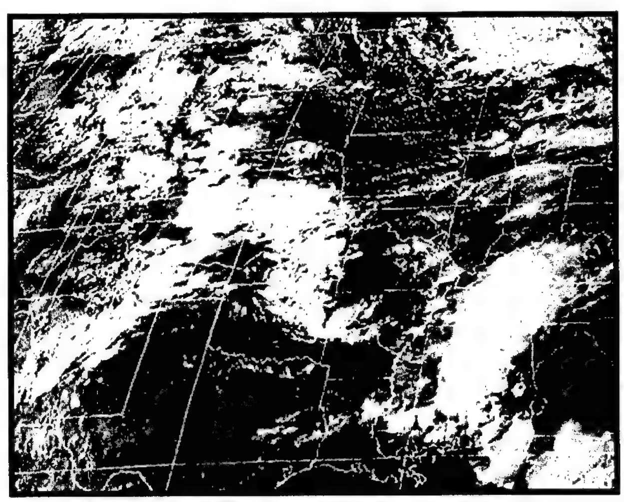

**Figure 4-31. GOES East Visual, 2315Z/20 July 2000.** Thunderstorms appear in a line on the lee side of the Rocky Mountains.

Figures 4-32 and 4-33 show the continuation of MCS nocturnal development as the system moves southward across the central Plains. Severe thunderstorms continued along the leading edge of the MCS during the early morning hours. In Figure 4-33, the MCS has taken on a circular (or round) appearance and can be classified as a MCC (as presented earlier in the MCC definition on page 32).

By early daylight, (Figure 4-34; six hours later from Figure 4-33) the MCC (has moved over Arkansas and southern Missouri and has lost its roundness (see arrow; has now become a MCS). It has now aligned north to south to fit the PVA lobe shown in the insert (reduced from Figure 4-28).

Figure 4-35 is a display of severe thunderstorm occurrences from 20/1000Z to 21/0600Z July 2000 and includes all reports from the MCCs/MCSs just presented. Verification reports during this 20-hour period included: 8 tornadoes, 48 convective gusts, 125 wind damage reports and 87 hail reports. Nearly all of the severe reports shown over Arkansas, Tennessee and Alabama are from the first thunderstorm complex presented earlier. Severe reports with the second MCC/ MCS are shown over the western Great Plains and Colorado region. They occurred later in the period mainly during the afternoon of the 20th and were mainly

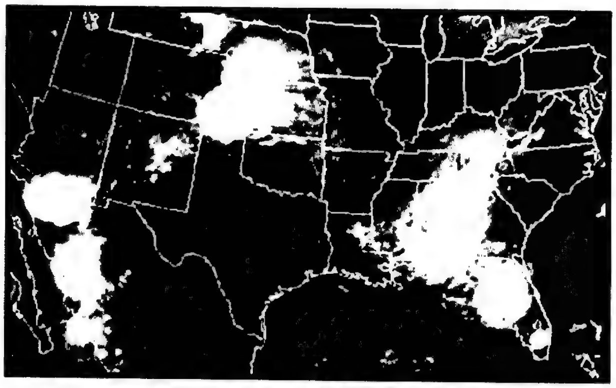

**Figure 4-32. GOES East Infrared, 0245Z/21 July 2000.** Thunderstorm line has organized into a MCC.

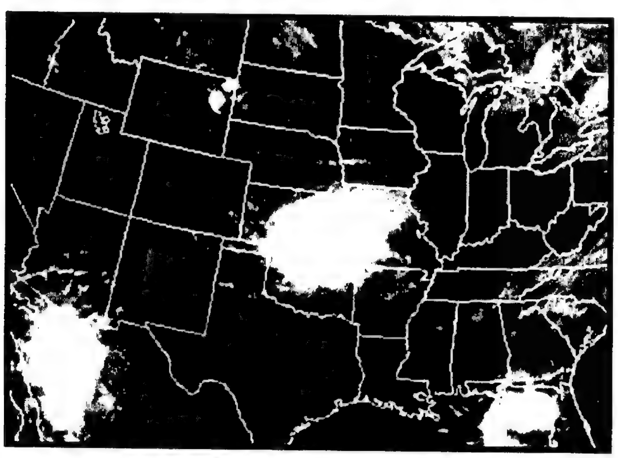

**Figure 4-33. GOES East Infrared, 0845Z/21 July 2000.** An excellent example of a mature MCC.

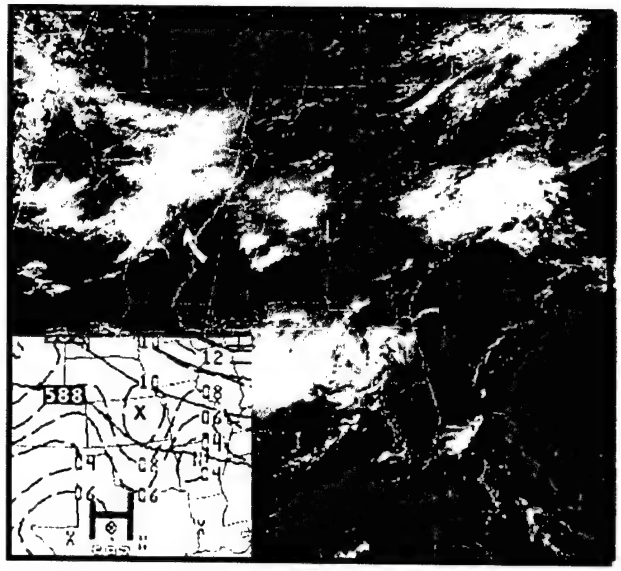

**Figure 4-34. GOES East Visual, 1432Z/21 July 2000.** MCS over Arkansas aligns with the ETA 12-hour forecast shown in the insert.

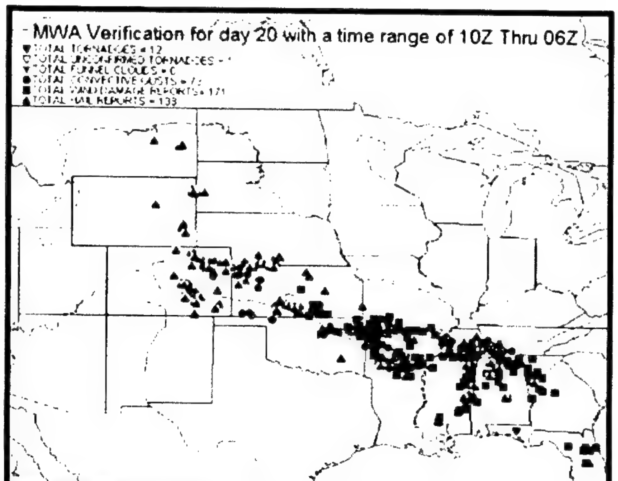


**Figure 4-35. Severe Weather Reports Military Weather Advisory 20B 20/1000Z to 21/0600Z July 2000.** Arkansas, Mississippi and Alabama reports were shown earlier Figure 4-26.

convective gusts and hail. The severe thunderstorms follow a northwest to southeast track indicating northwest flow. These northwest flow thunderstorm complexes can produce Derechos such as shown in Figure 4-35 over the lower Mississippi Valley area.

The third MCS event in this series occurred within 24 hours of the MCS/MCC that was just presented. In Figure 4-36, the 12-hour ETA forecast shows positive vorticity on the north side of the subtropical ridge over the northern Rocky Mountains as indicated by the arrow. This PVA moved southeastward over Wyoming when it entered the northwest flow.

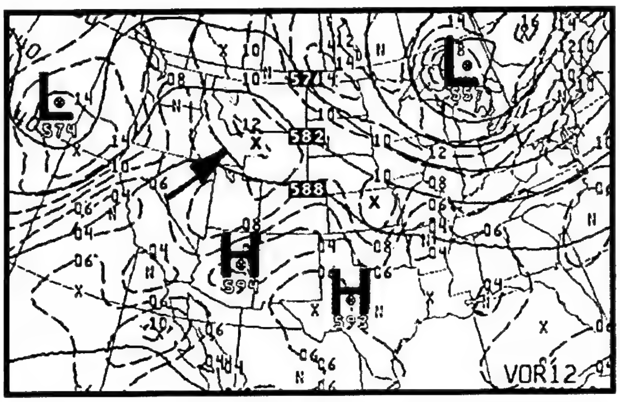

**Figure 4-36. ETA 12-Hour Forecast 500-Mb Heights/ Vorticity, 1200Z/21 July 2000.** PVA lobe on the northern side of the subtropical ridge

Figures 4-37 and 4-38, respectively, depict the ETA initial analysis and 12-hour forecast. As the reader can see in Figures 4-37 and 4-38, the strengthening Northern

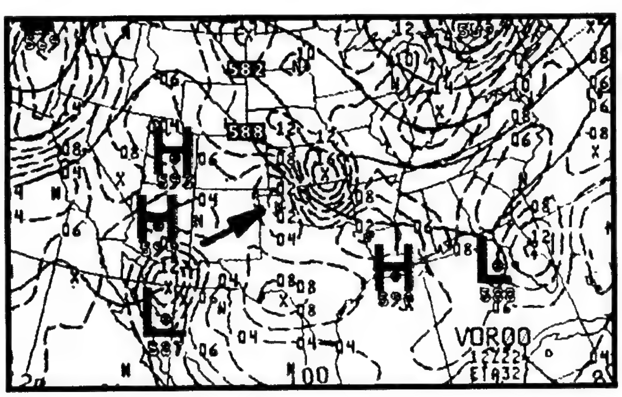

**Figure 4-37. ETA 500-mb Heights/Vorticity Analysis, 1200Z/22 July 2000.** PVA lobe has moved rapidly southward into the central Plains

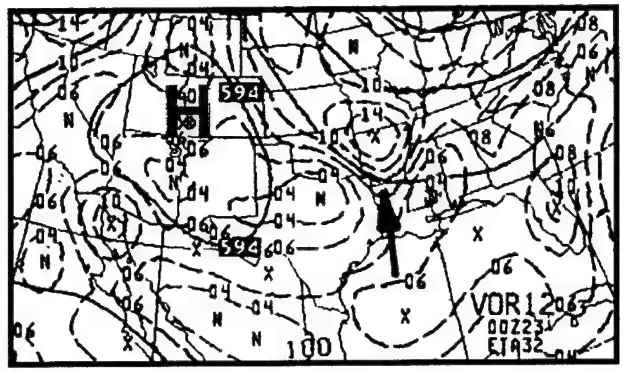

**Figure 4-38. ETA 12-Hour Forecast 500-mb Heights/ Vorticity, 0000Z/23 July 2000.** PVA has entered the lower Mississippi Valley

Rockies system has moved rapidly southward into the central Great Plains. This system is forecast to follow approximately the same track as the previous two systems and will bottom out in the trough over Arkansas and the lower Mississippi Valley area. Notice that the western CONUS subtropical ridge continues to amplify with each MCS system.

Figures 4-39 through 4-42 illustrate a third mesoscale thunderstorm system that affected the Great Plains within a 48-hour period.

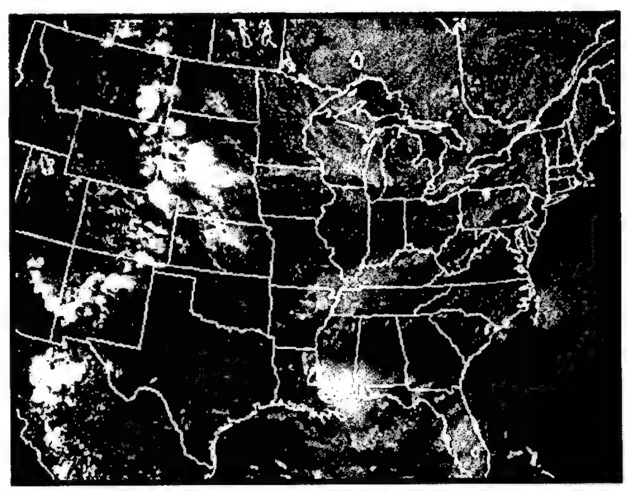

**Figure 4-39. GOES East Visual, 2215Z/21 July 2000.** Mid-afternoon thunderstorms have developed east ofthe Montana/Wyoming Rockies and eastward.

The nocturnal MCS continues to grow and monsoon moisture appears to be feeding into the system over western Kansas and Oklahoma as shown in Figure 4-40.

In Figure 4-41, the system has taken on a roundness feature. In Figure 4-42, the system is becoming elongated to fit the ETA 12-hour forecast shown in the insert (noted by the arrow). Figure 4-43 depicts the severe weather reports received in AFWA's CONUS Severe Weather Unit. Most of these events occurred during the late afternoon and early evening.

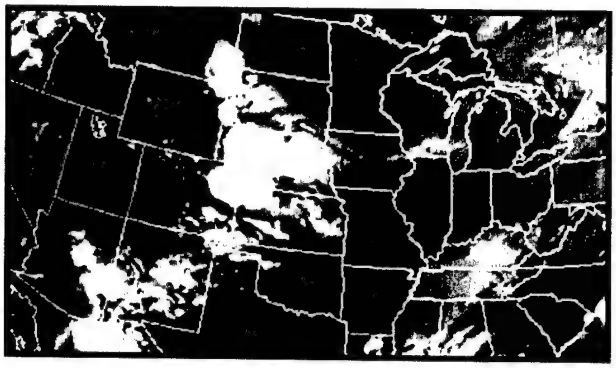

**Figure 4-40. GOES East Infrared, 0115Z/22 July 2000.** Thunderstorms continue to expand over the western Great Plains

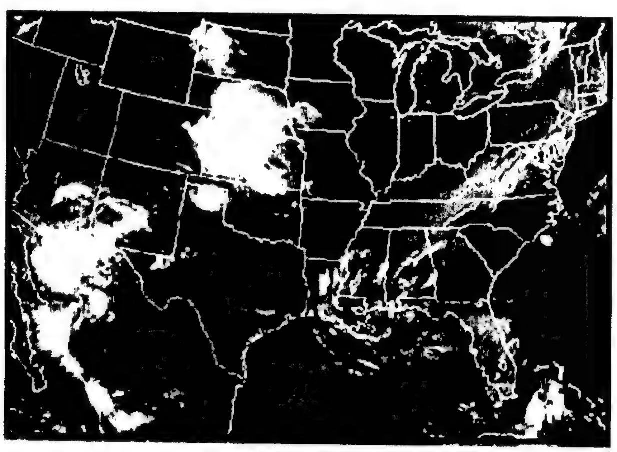

**Figure 4-41. GOES East Infrared, 0515Z/22 July 2000.** A MCS has formed and appears round

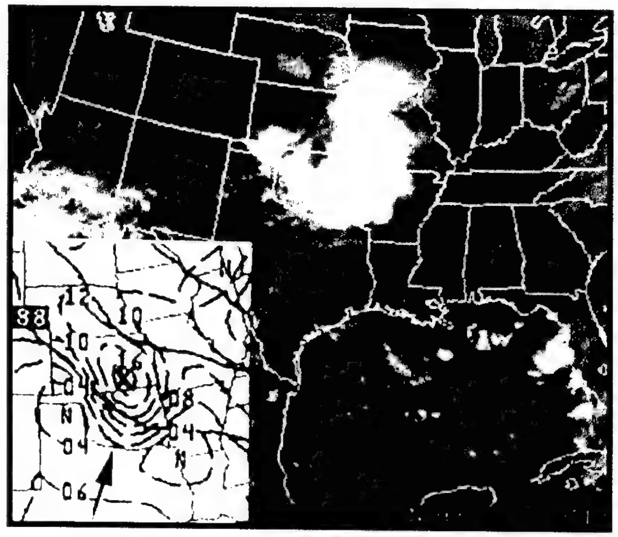

**Figure 4-42. GOES East Visual, 1345Z/22 July 2000.** Thunderstorm system is becoming elongated.

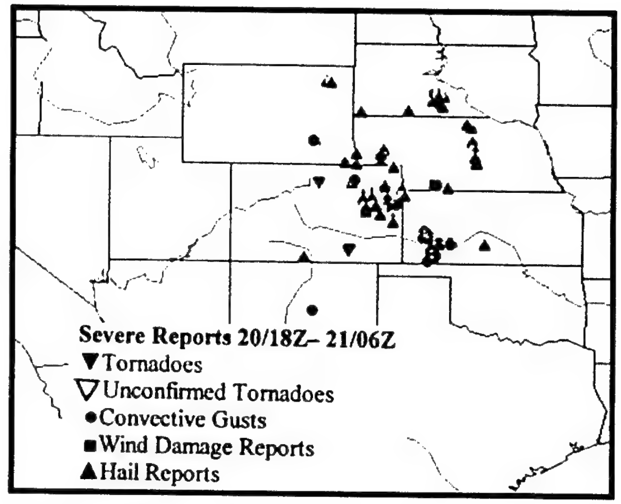


**Figure 4-43. Severe Thunderstorm Reports Military Weather Advisory 20C.** Valid time for this advisory was 1800Z/20 July to 0600Z/21 July 2000.

Figures 4-44 and 4-45 depict the lightning strike summaries associated with the third MCS. Northwest upper flow is obvious as seen by the orientation of the strikes.

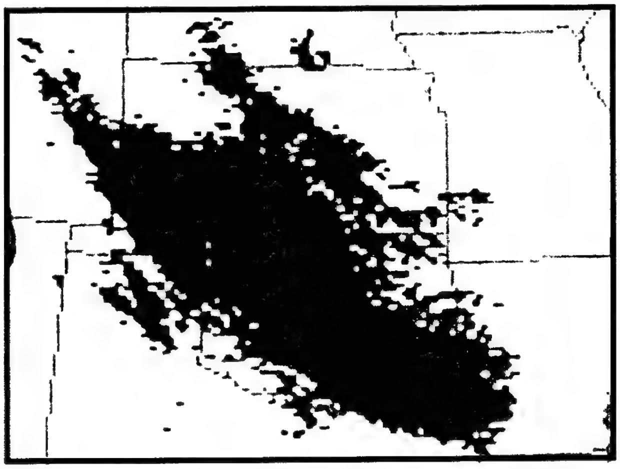

**Figure 4-45. Lightning Strike Display, Valid 22/0400Z – 22/1600Z.**

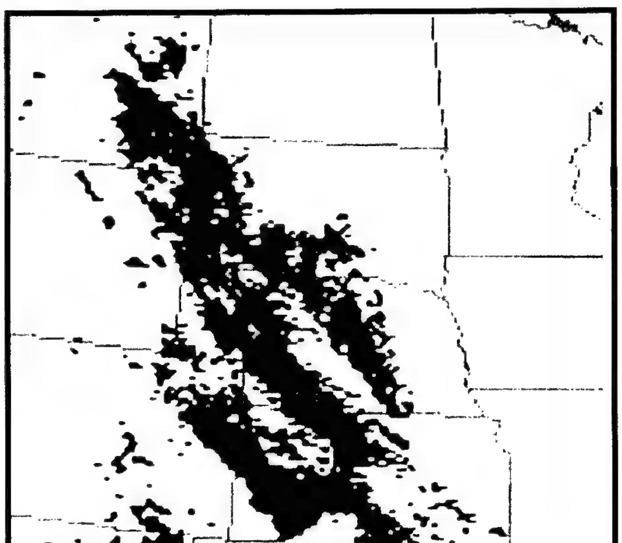

**Figure 4-44. Lightning Strike Display, Valid 21/1800Z – 22/0600Z.**

It can be difficult to locate these small short waves (within northwest flow) that produce MCSs or MCCs when one looks at conventional analysis such as shown in Figures 4-46 and 4-47. Weak thermal troughs and a few degrees of change in the wind direction may be the only clues. As shown in these examples, forecasters should focus their attention on the positive vorticity field during the weak gradients of summer.

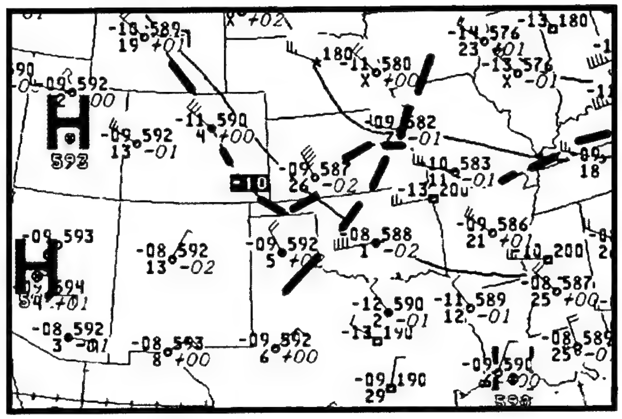

**Figure 4-46. 500-mb Analysis, 1200Z/22 July 2000.** A weak trough is associated with the MCS shown in Figure 5-42.

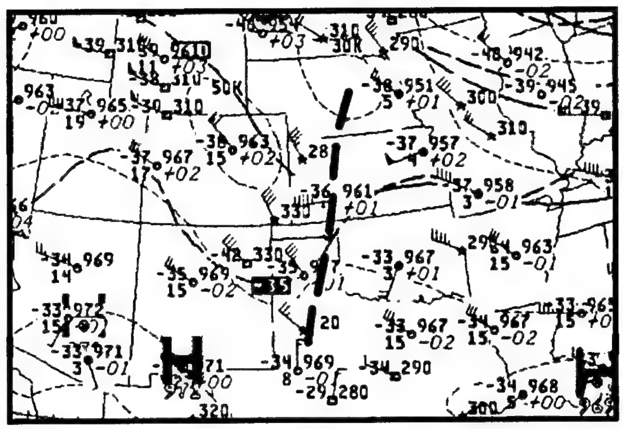

**Figure 4-47. 300-mb Analysis, 1200Z/22 July 2000.** Trough appears better defined at the 300-mb level.

An example of several frontal MCSs is shown in the following IR illustrations. None of the small MCSs attained the criteria of a MCC presented earlier. The related 500-mb chart is depicted in Figures 4-48. In Figure 4-48, the wind flow over the thunderstorm areas

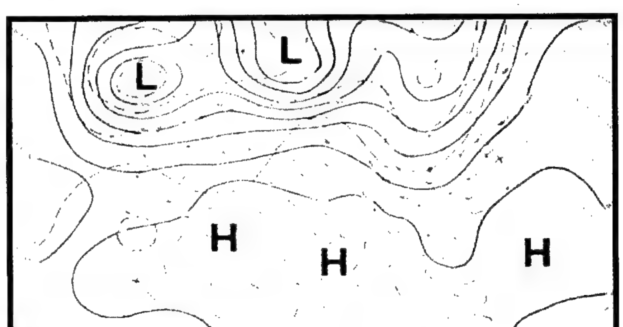


**Figure 4-48. 500-mb Analysis, 1200Z/19 July 1982.** The figure shows a subtropical high over southern Great Plains.

is from the southwest; the subtropical ridge extends across the southern CONUS. (MCCs generally occurred within a mid-level west to northwest wind flow).

Figure 4-49 shows the related surface chart. Figures 4-50 and 4-51 show nocturnal MCSs systems prior to 1200Z. Small thunderstorm systems developed along

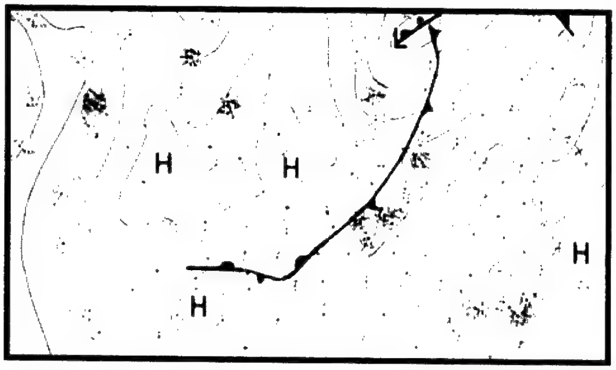


**Figure 4-49. Surface Analysis, 1200Z/19 July 1982.** The cold front is becoming stationary.

**Figure 4-50. Infrared (MB), 0300Z/19 July 1982.** Several MCSs developed along front.

**Figure 4-51. Infrared (MB), 0600Z/19 July 1982.** MCSs continue along front.

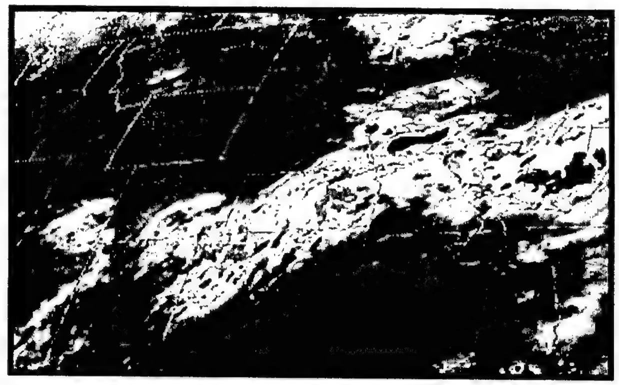

**Figure 4-52 Infrared (MB), 1200Z/19 July 1982.** Thunderstorms have weakened.

the cold front. By 12Z, Figure 4-52, the thunderstorms weakened.

When the subtropical high persists over a given area for several days or longer then a heat wave and significant mid-level capping of convection will begin underneath the warm core high. Figure 4-53 depicts a capped environment over the Great Plains. The subtropical high is located over the central plains. Cumulus streets aligned with the low-level flow have formed but will not develop further. Monsoonal thunderstorms are evident over the Rockies on the western side of the subtropical high. Likewise, thunderstorms have developed over Arkansas and Louisiana on the eastern side within an uncapped environment. Inversions become stronger day-by-day resulting in continued low-level warming within the stagnant air mass. Persistent heat waves can have disastrous results on the population, animal and plant life.

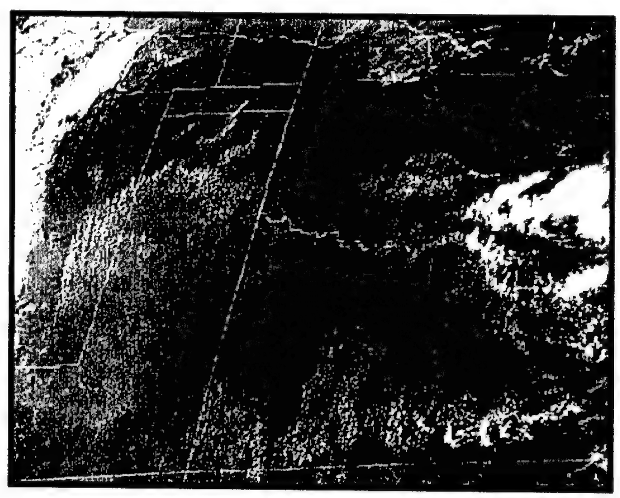

**Figure 4-53. Visible, 2032Z/09 July 1998.** A capped environment over the Great Plains.

Heat waves often begin over the western and central Great Plains when relatively hot air (a result of adiabatic warming) moves out of the mountains. A southwest flow over the Great Plains advects the air eastward as seen in Figure 4-54. These thermal axes occur almost daily over the intermountain regions throughout the summer and appear on the standard 850-mb chart (Figure 4-54). Cold fronts from the Pacific Northwest have a hard time penetrating these blocking ridges and low-level thermal axes and become stationary across Idaho and Wyoming or dissipate. When intrusions of this hot air advects across the Great Plains (see heavy arrow in Figure 4-54) and a subtropical ridge is located above this advection, then a heat wave and capping is established. Daily maximum surface temperatures exceed 100 degrees. The heat wave may last several days to several weeks until the subtropical ridge/high shifts to another part of the country.

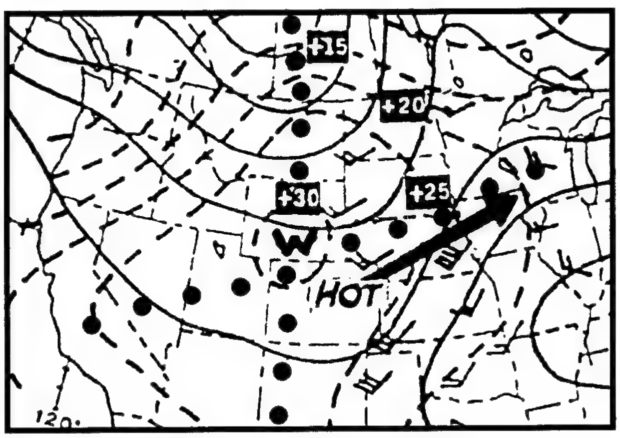


**Figure 4-54. 850-mb Analysis, 1200Z.** Thermal axes are indicated by red dots. Hot downslope winds advect heat eastward.

In a second example of capping, Figure 4-55 shows a typical hot, capped atmosphere over the Great Plains. This mid afternoon photo shows anticyclonic streets of cumulus over most of the Great Plains. The subtropical high is located over southwestern Missouri. Monsoon moisture appears over the western CONUS. Thunderstorm clusters have developed within northwest flow over Michigan, northeastern Iowa and Illinois and are associated with a short wave. One lonesome short-lived thunderstorm appears near Lincoln, Nebraska that developed along a stationary front and on the southwestern end of the short wave. Convection is also noted over Texas and Louisiana on the bottom side of the subtropical high (cooler midlevel temperatures).

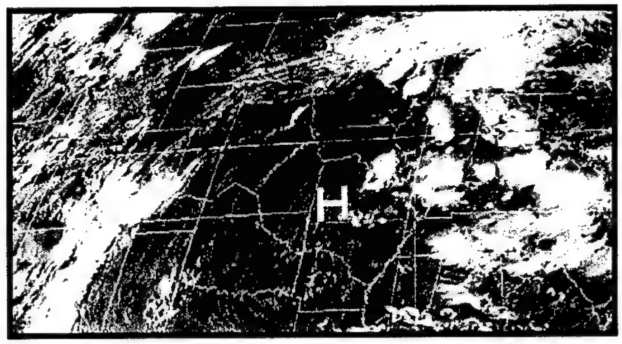


**Figure 4-55. Visible, 2215Z/20 July 1999.** Strong capping over the Great Plains.

The related 700-mb chart (Figure 4-56) shows a warm pocket with temperatures of >10°C. As a general empirical rule, the 700-mb > +10°C appears to be the temperature(s) to use for capping east of the Rocky Mountains. A 700-mb temperature of +12°C is generally used for capping over the western Great Plains due to the higher elevations. In Figure 4-56, the core of the hot air is shown over Colorado and Wyoming with temperatures of +14°C. These mid-level warm temperatures over mountainous areas do not deter monsoonal thunderstorm development due to strong orographic lifting and heating. Comparing the convection areas shown in Figure 4-55 to the 700-mb analyses, it can be seen that thunderstorms developed generally along the +10°C threshold or lower.

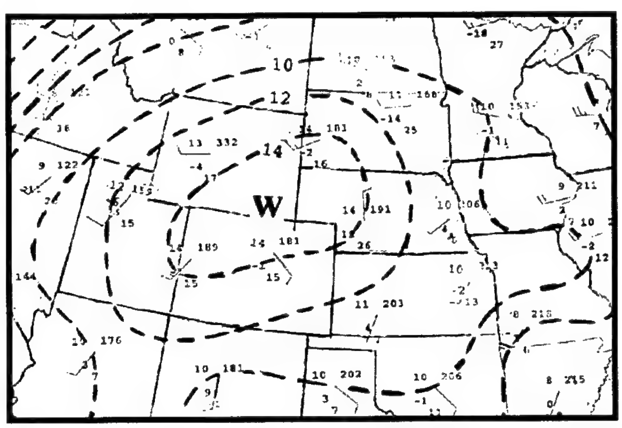


**Figure 4-56. 700-mb Analysis, 1200Z /20 July 1999.** Strong warming over the central CONUS.

Along with heat and humidity, widespread haze and other pollutants (such as smoke from forest fires) may persist due to the weak, stagnant airflow of the subtropical high. Morning haze and fog become totally

haze by late morning. In the Figure 4-57, one can easily see the extent of haze east of the Rocky Mountains (see arrows). Frontal clouds lie across South Dakota, and monsoon clouds cover a large area of the western CONUS. The milky sky often hides developing convection during the afternoon. Haze persists and thickens until the warm core ridge/high shifts to another part of the country.

**Figure 4-57. Visible, 1430Z/06 September 1998.** Widespread haze east of the Rockies.

**Subtropical High Locations - Western or Eastern CONUS.** So far in this section, discussions pertained to weather regimes associated with the subtropical high when it is established over the central Great Plains. The following paragraphs described general frontal activity and weather conditions over the central CONUS when the subtropical high appears either east of the Mississippi Valley area or west of the Rocky Mountains

Subtropical highs, located over the eastern CONUS and/or over the western CONUS, as shown in these early August 500MB and surface charts, Figures 4-58a through 4-59b, bring a return to westerly upper flow and an increase in frontal activity over the central CONUS.

Cold fronts will move southward into existing moist and unstable air masses and result in frequent severe thunderstorm outbreaks across the central and southern Great Plains. Also, when the subtropical ridge is suppressed southward over the southern CONUS cold fronts are able to move southward into the central and southern Midwest where they eventually become stationary. Daily severe thunderstorm outbreaks occur along these boundaries within a hot, moist and unstable air mass.

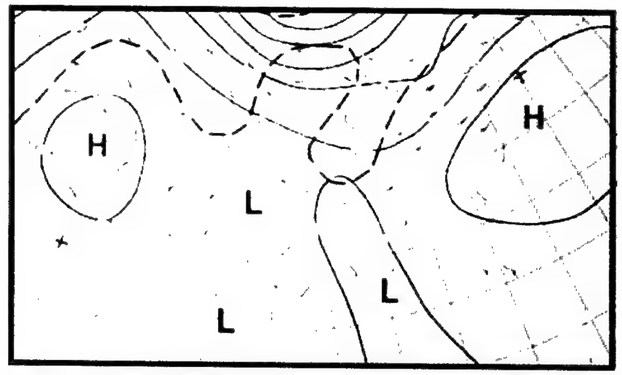


**Figure 4-58a. 500-mb analysis, 1200Z/Early August.** Subtropical high is over western and eastern CONUS.

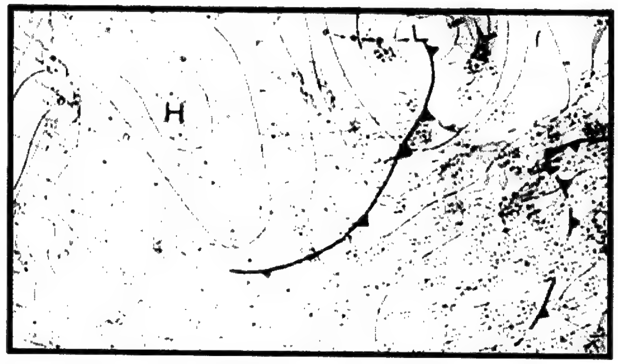


**Figure 4-58b. Surface Chart, 1200Z/Early August** Cold front moving southward over the central CONUS.

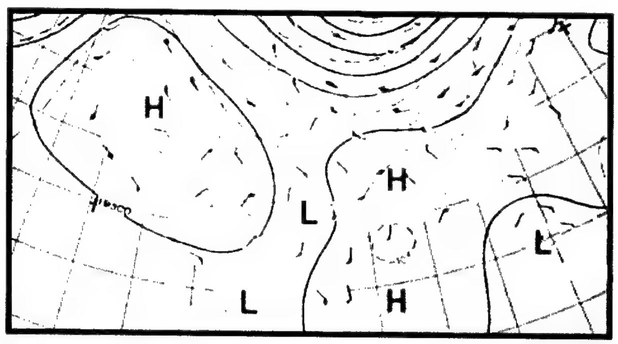


**Figure 4-59a. 500-mb Analysis, 1200Z/03 August 1978.** Subtropical high is over western CONUS.

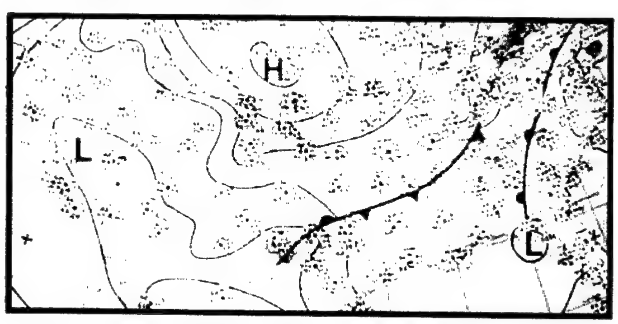


**Figure 4-59b. Surface Chart, 1200Z/03 August 1978.** Cold front moved into southern CONUS in early August.

## Subtropical High Locations - Western or Eastern CONUS

Although most discussion in this publication deals with subtropical ridge systems, there occasionally will be a storm system such as shown in Figure 4-60 that will produce thunderstorms and heavy rainfall over a large area of the CONUS. Figure 4-60, an early August photo, shows a pattern over the Great Plains more commonly found during spring and fall. In this example, a strong upper trough was located over the central CONUS (see 500-mb charts Figures in 4-58a and 4-59a previous page —not related to Figure 4-60). As one can see in the photo, frontal thunderstorms cover a large area of the central CONUS with plenty of low-level moisture, heat and instability.

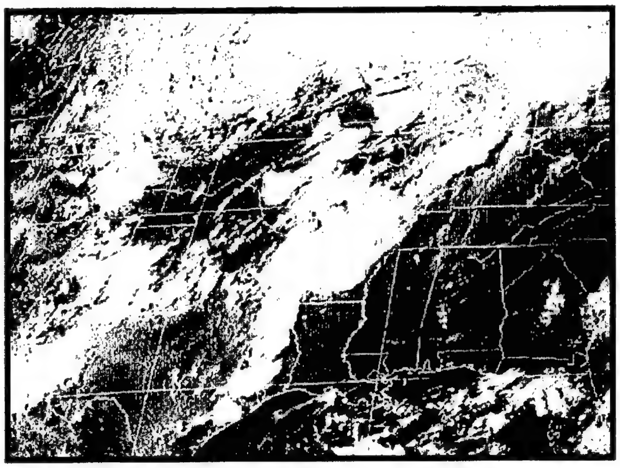

**Figure 4-60. Visible, 2302Z/03 Aug 1998.** Strong storm system over the central CONUS.

When the subtropical ridge/high location is over the Mississippi Valley area, cold fronts emerging from the Rocky Mountains often decelerate or become stationary and are aligned northeast to southwest over the central plains due to a southwesterly flow aloft. The following satellite sequence, Figures 4-61a through 4-61d, illustrates an event. In many cases studied, cold frontal severe thunderstorms will break out by mid morning over the northern Great Plains and/or Great Lakes where there is stronger upper support and stronger shear (Figures 4-61a/4-61b; noted by the arrow in Figure 4-61a). Thunderstorms often develop along the southern portion of the cold front by mid afternoon (Figure 4-61c) during maximum heating where there are strong CAPES and surface based lifted (not capped). Severe thunderstorms are likely as surface convergence, moisture and strong surface heating are in place.

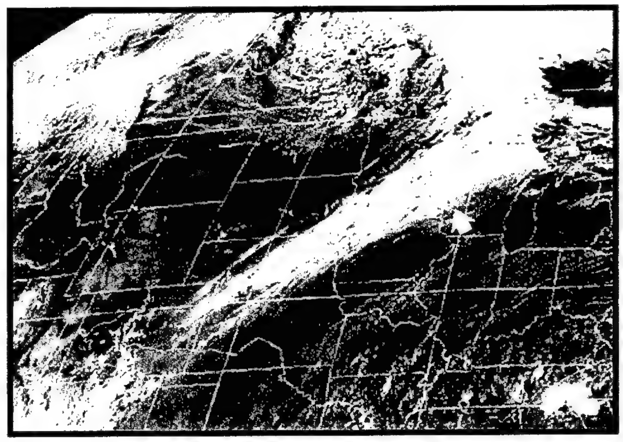

**Figure 4-61a. Visible, 2045Z/05 July 1999.** Thunderstorms over Minnesota and Wisconsin Frontal band across central Great Plains.

**Figure 4-61b. Visible, 2125Z/05 July 1999.** Convection enhancing over western Kansas.

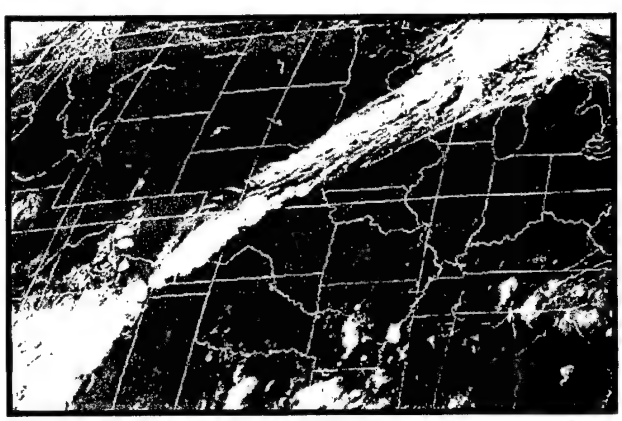

**Figure 4-61c. Visible, 2340Z/05 July 1999.** Taken approximately two hours after Figure 4-61b, this photo shows the merging of northern and southern thunderstorm areas.

Finally in Figure 4-61d, an extensive thunderstorm line has developed along the entire cold front in less than four hours. No conventional data was available. Four severe occurrences over western Wisconsin and eastern Minnesota was reported between 1400Z and 1800Z; sixty-three severe thunderstorms were reported along the cold front from eastern Colorado to Wisconsin between 1800Z and 0100Z. All reports received were either hail or wind damage.

**Figure 4-61d. Visible, 0045Z/ 06 July 1999.** One hour after Figure 4-61c, this photo shows thunderstorms have developed all along the boundary.

**Rocky Mountain Thunderstorm Events.** Thunderstorms occur frequently over the Rocky Mountains during the summer and generally begin by early afternoon. They will go through their life cycles while remaining over the mountains when the steering winds are unfavorable for eastward movement into the lee-side trough. However, if the steering winds are westerly and if there is no upper support, (trough, PVA) then thunderstorms are likely to move off the mountains by late afternoon and diminish with surface heating over the plains of eastern Colorado and Wyoming. However, if there is upper support then thunderstorms will organize into lines by late afternoon as they move off the mountains as shown in Figure 4-62.

Central Plains' forecasters should monitor the development and movement of these lines especially when there is evidence of weak short waves and/or weak PVAs and cold troughs. The thunderstorm lines often intensify within the lee-side trough (a convergent zone) and continue to grow as they encounter hot, moist and unstable air east of the leeside trough. The absence of the lee-side trough will allow Great Plains low-level moisture to advect westward to the Front Range especially during the morning hours when the winds are from a southeasterly direction. Easterly moist upslope flow and a thermal axis will likely produce strong (and severe) thunderstorms over the plains of eastern Colorado and Wyoming during the heating hours. Forecasters briefing aircrews east of the Front Range of the Rocky Mountains during the summer should be aware that this area is often subject to frequent hailstorms—sometimes severe.Let's look at an occurrence of a Rocky Mountain event that tracked across the Great Plains during the nighttime. In the

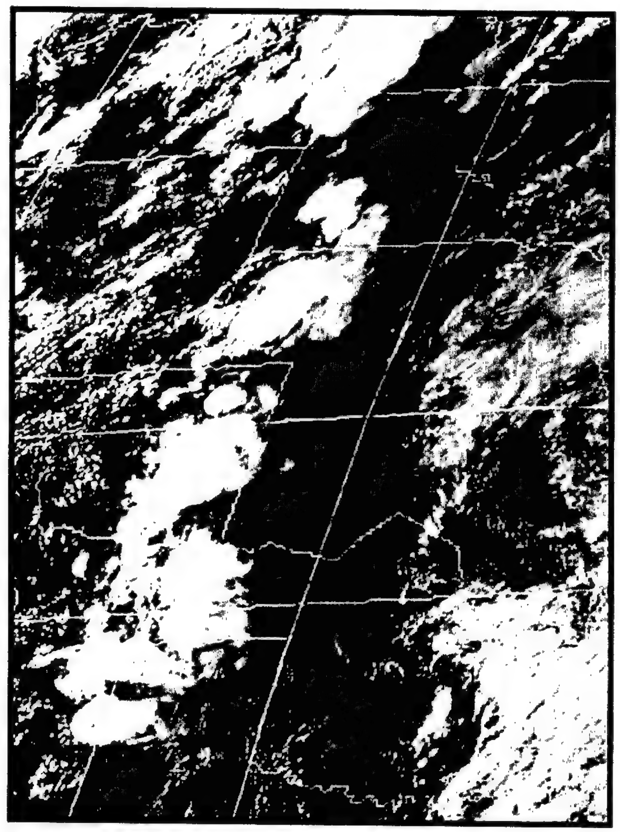

**Figure 4-62. Visible, 2332Z/25 June 1999.** Thunderstorm line has moved off the mountains.

500-mb analysis, Figures 4-63 and 4-65 note the weak pressure and thermal troughs (see arrows) within west-north-west flow over Colorado and Wyoming. At the surface, Figures 4-64 and 4-66, no frontal systems were evident over the Rocky Mountains or western Great Plains.

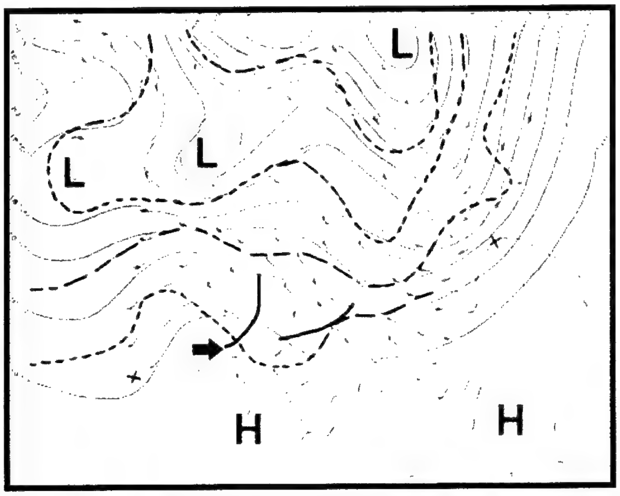


**Figure 4-63. 500-mb Analysis, 1200Z/24 June 1979.** Weak trough over the Rockies within northwest flow.

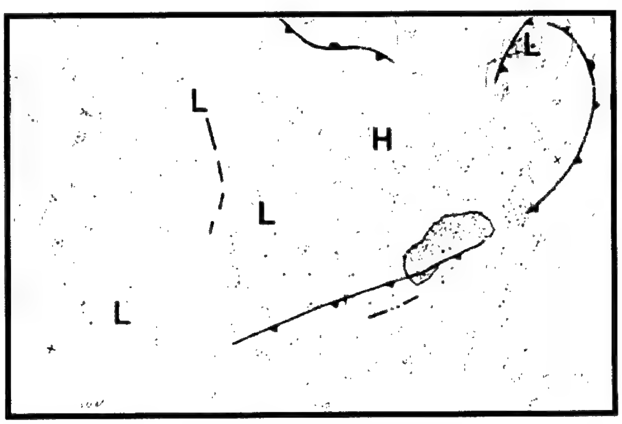


**Figure 4-64. Surface Analysis,1200Z/24 June 1979.** Surface trough over the Rockies. Easterly winds advected Plains moisture to the mountains.

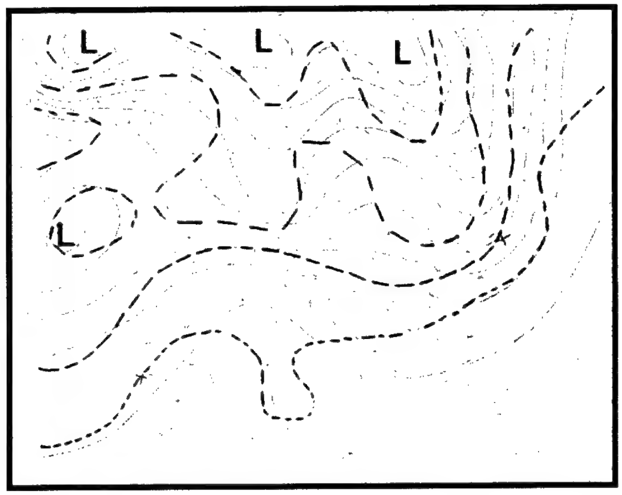


**Figure 4-65. 500-mb Analysis, 0000Z/25 June 1979.** 12 hours after Figure 4-63. Weak thermal trough where thunderstorm line developed.

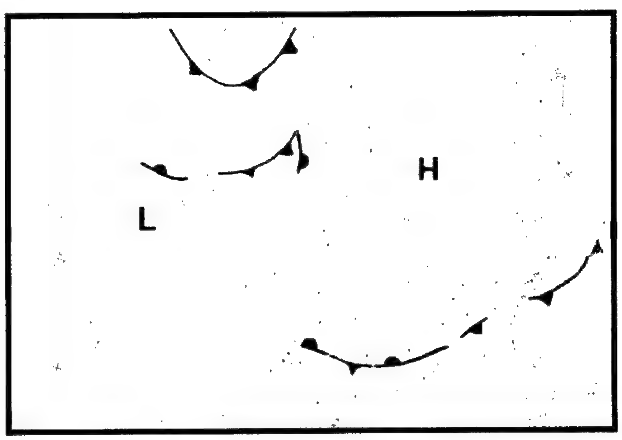


**Figure 4-66. Surface Analysis, 0000Z/25 June 1979.** Surface trough is stationary; Thunderstorms have developed over western Plains.

Convection developed by 1800Z over the Rocky Mountains as noted by the arrow in Figure 4-67. Two hours later, Figure 4-68, a thunderstorm line has developed over the Rocky Mountains—another thunderstorm cluster developed over western South Dakota (noted by the arrow in Figures 4-67 and 4-68). The line has grown and merged with other cells over South Dakota and extends from the Texas Panhandle to North Dakota as it moved eastward into moist and unstable air (Figure 4-69).

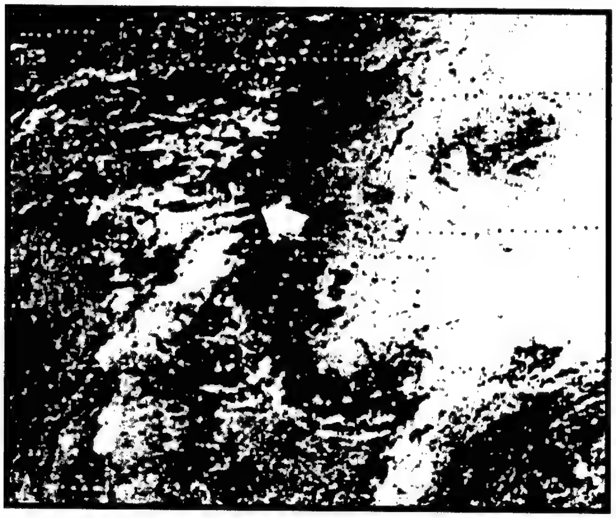

**Figure 4-67. Visible, 1816Z/24 June 1979.** Convection develops over the Colorado Rockies.

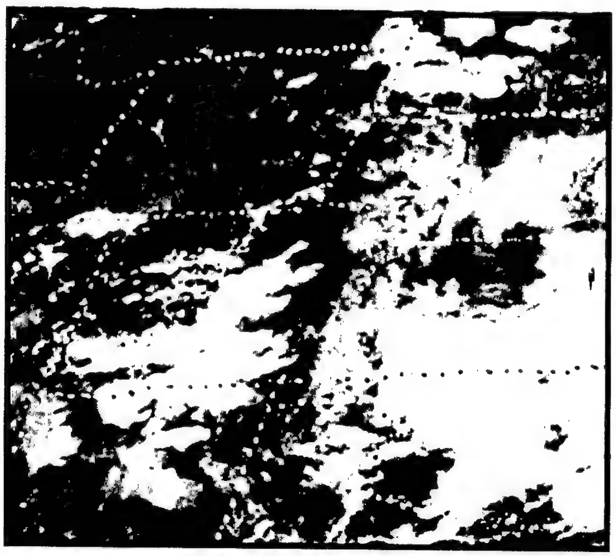

**Figure 4-68. Visible, 2016Z/24 June 1979.** Thunderstorm line has moved off the Colorado Rockies.

These lines often continue eastward and regenerate as they encounter the southerly low-level jet, and moist, unstable air ahead of the line throughout the evening and early morning hours; as shown in the IR photo (Figure 4-70; eight hours later than Figure 4-69). In Figure 4-70, the nocturnal thunderstorm line is moving across the central Great Plains. Generally, these lines begin to fall apart as they dissipate a few hours before

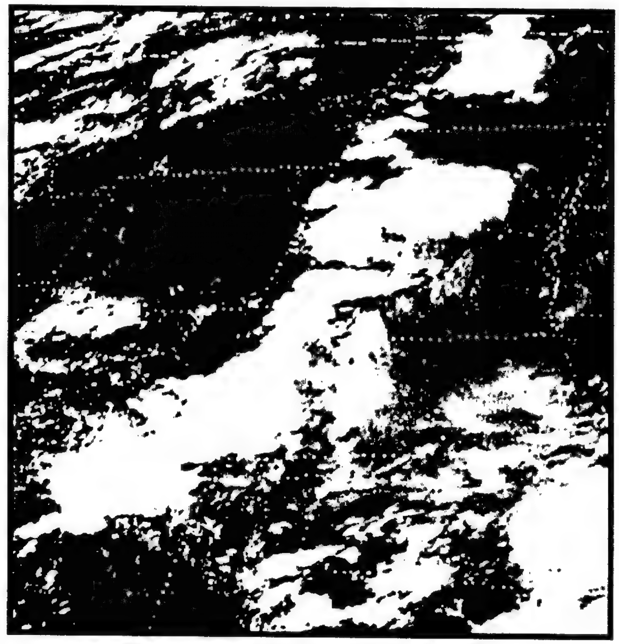

**Figure 4-69. Visible, 2316Z/24 June 1979.** Thunderstorm line continues to grow. The line has moved into the western Great Plains.

**Figure 4-70. Infrared (MB), 0716Z/25 June 1979.** Eight hours later from Figure 4-69, the thunderstorm line continues eastward.

sunrise. Figure 4-71, a noontime photo, shows what is left of the line over eastern Nebraska, Kansas and Oklahoma (noted by C). The continued presence of weak impulses may sustain dissipating areas until convection redevelops later in the afternoon. This example of Rocky Mountain development, (and mesoscale thunderstorm complexes/systems presented earlier) which subsequently tracks across the Great Plains throughout the night, are responsible for many of the nocturnal thunderstorms that affect the Midwest.

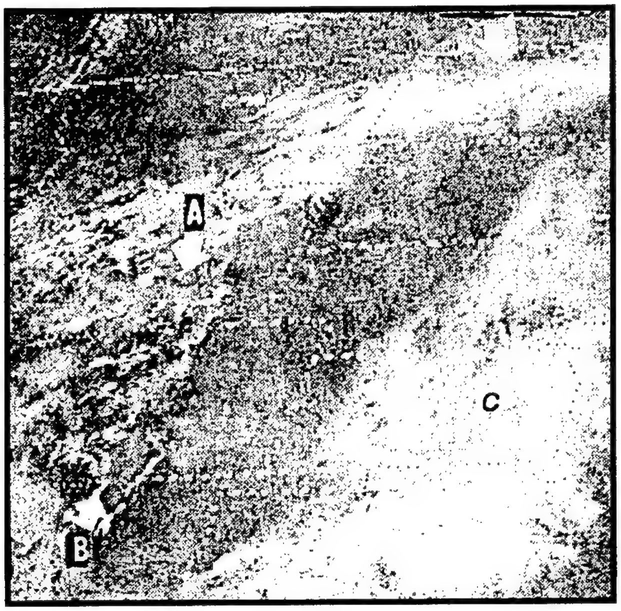


**Figure 4-71. Visible, 1816Z /25 June 1979.** Eleven hours later from Figure 4-70. Thunderstorm line dissipated over central Plains. Convection develops over the Rockies.

Daytime thunderstorms across the Great Plains do occur during July and most of August when an active cold front moves through or if an east-west stationary front is overrun by moist southerly gulf flow. However, late afternoon and nocturnal thunderstorms are prevalent during the summer months. When the subtropical high shifts southward into the southern Great Plains and lower Mississippi Valley area then a westerly to northwesterly upper level flow begins. Cold fronts are able to drift southward into the central plains where they eventually become stationary and interact with a hot, moist and unstable air mass. Widespread severe weather breaks out along the boundary within a divergent northwest mid and upper flow. Thunderstorms that develop and move over the same locations over a period of time will produce heavy rains (train echo effect); this usually happens along stationary fronts or convergence boundaries.

The quote from AWSTR 200 (Rev) is presented again to remind forecasters: "There is little doubt that the most destructive severe weather outbreaks in the summer are associated with southeastward moving surface cold fronts and/or a west-northwest to northwest flow in the mid-troposphere.

The springtime regime of dry line thunderstorms that develop over western Texas northward to western Nebraska during the afternoon and move across the plains during the night **may occur** if the upper flow and dynamics are favorable. However, with subtropical ridging and weak wind, thermal fields (and perhaps capping) in place over the central Plains, then dry line development is usually confined to the western Great Plains.

**Low-Level Jet and Stratus Advection.** The Great Plains nocturnal low-level jet weakens through the summer, but it is sufficiently strong for daytime gusty surface winds, low-level moisture advection and nocturnal thunderstorm development. Strong (non-convective) gradient wind outbreaks (>35 knots) may occur in early or late summer but strong winds are rare for most of the period. The advection of stratus from Texas into the central and upper Midwest terminates during mid-June although moisture tongues continue within southerly flow throughout the summer. In Figure 4-72, a noticeable tongue of gulf moisture (in the form of cumulus streets) extends northward from eastern Texas to eastern Nebraska and western Iowa (noted by the arrows).

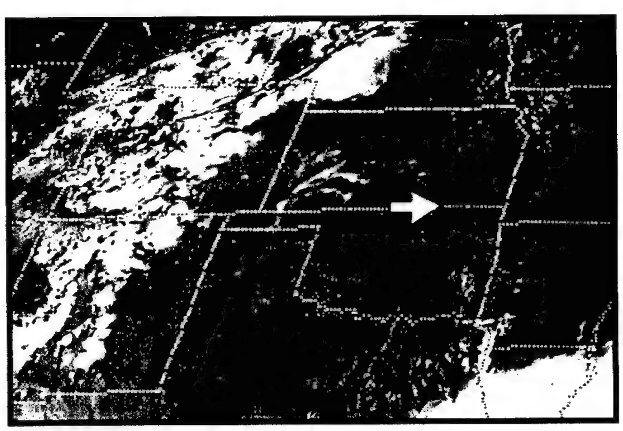

**Figure 4-72. Visible, 2130Z/23 June 1981.** Moisture tongue from Texas to Nebraska and Iowa.

Stratus is generally confined to Texas during the morning hours and develops into cumulus by early afternoon due to surface heating. Stratus does not advect into Texas from the Gulf of Mexico as an identifiable cloud mass, but rather, stratus forms over the rising terrain of southern Texas (often in the San Antonio-Austin area) usually between 0700Z and 1100Z with a light moist wind flow (Figure 4-73). Stratus formation and advection may occur as long as this flow continues but the area remains patchy with ceilings less than 2000 feet. In the morning visible photo, Figure 4-74, stratus may be seen over north central Texas; it formed in the area around San Antonio and Austin earlier in the morning. Several hours later, Figure 4-75, note that stratus changed into lines of cumuliform clouds with ceilings greater than 2500 feet.

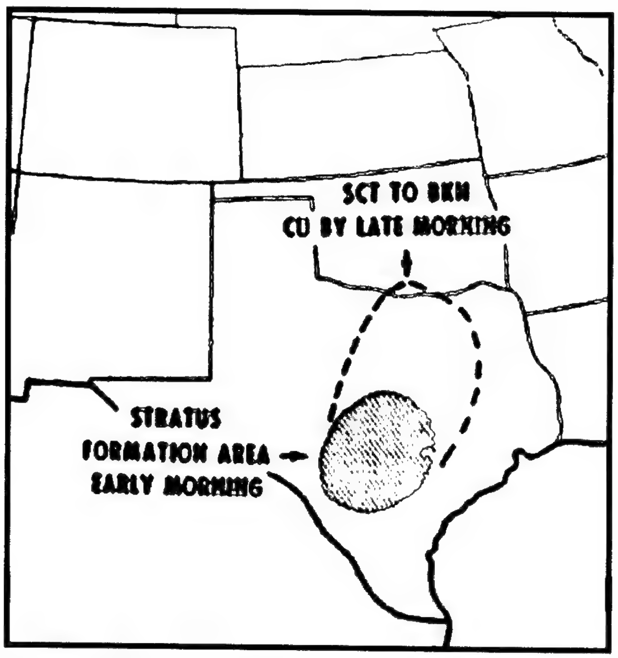


**Figure 4-73. Stratus Formation/Advection.** Stratus develops over rising terrain San Antonio/Austin area.

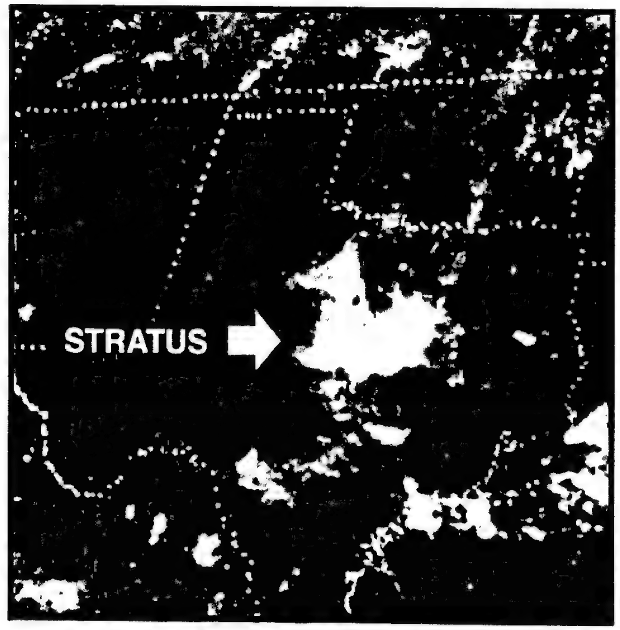


**Figure 4-74. Visible, 1416Z/27 June 1979.** Nocturnal stratus is dissipating.

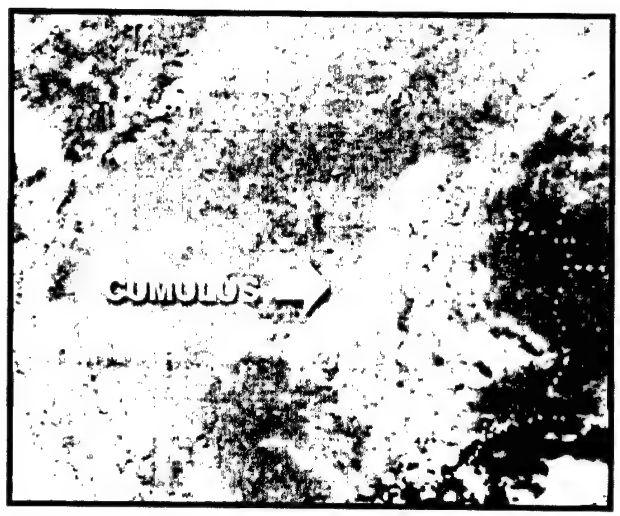

**Figure 4-75. Visible, 1746Z/27 June 1979.** Three and one-half hours later from Figure 4-74, stratus changed to cumulus.

**Gulf Coast Sea/Land Breeze Thunderstorms.** Thunderstorm development is likely within the upper-level easterly flow on the southern side of land based, heated, subtropical ridges/highs, usually along the Gulf Coast and across the northern Gulf of Mexico as shown in the late afternoon visible photo, Figure 4-76. In this example, Figure 4-77, the subtropical high is located over the eastern Oklahoma on the 500-mb analysis. Mid-level temperatures are slightly cooler on the southern side making lapse rates steep enough for convection. Upper-level inverted troughs or weak lows are sometimes observed across the northern Gulf of Mexico and would help sustain convection. Additionally, sea breezes along the Gulf Coast enhance thunderstorm activity as seen along the Gulf Coast in Figure 4-76.

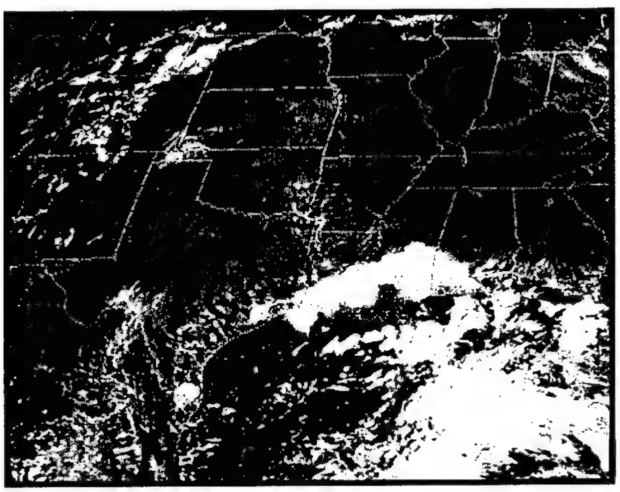

**Figure 4-76. Visible, 1830Z/23 June 1981.** Widespread convection across the Gulf coast and northern Gulf of Mexico.

Gulf Coast land breeze thunderstorms may occur along the coast and off shore during the nocturnal period. Convection often subsides toward morning when the sea breeze effect begins with surface heating. In Figure 4-78, 1200Z IR, nocturnal thunderstorms are located off the Florida Panhandle coast. Chapter 5 has more discussion on land and sea breeze activity (Eastern CONUS; Figures 5-24, through 5-28).

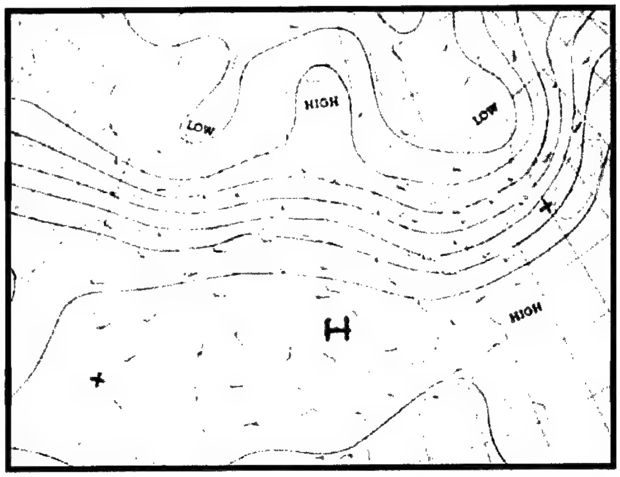


**Figure 4-77. 500-mb Analysis, 1200Z/23 June 1981.** A subtropical ridge extends across the entire southern CONUS.

The threat of tropical storms affecting the Texas and Louisiana coastal areas during mid and late summer should always be considered. Be suspicious of growing thunderstorm complexes in the Gulf of Mexico. More discussion and several examples of tropical systems affecting the western Gulf and adjacent coastal areas of Texas and Louisiana will be presented in Chapter 5.

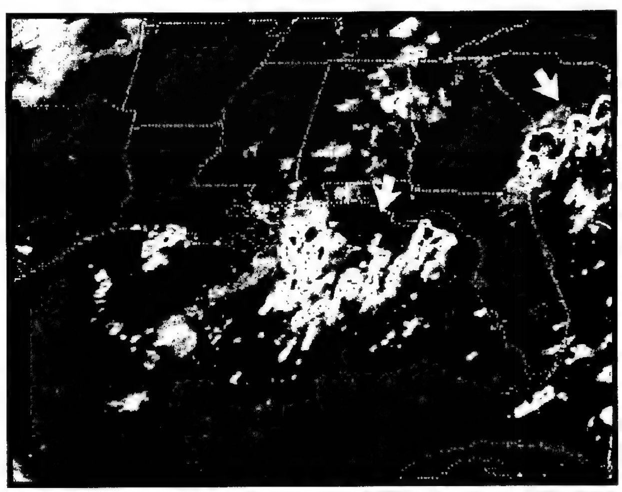

**Figure 4-78. Infrared (MB), 1201Z/18 July 1982.** The arrows denote offshore nocturnal thunderstorms.

*Summer Regimes*

## Chapter 5

# Eastern CONUS

**General.** The following regime discussion covers the area east of the Mississippi River to the East Coast and adjacent water areas. Continued subtropical high discussions and its effects over the eastern CONUS will be presented.

**Subtropical High over the Eastern CONUS.** Northeastern CONUS forecasters should be aware that thunderstorms associated with Canadian short waves will move along the periphery of the subtropical high (Dakotas/Minnesota/Wisconsin and northern Great Lakes) when the high is established to the south of their area as shown in Figure 5-1. The steering winds for convection would most likely be from the southwest over the Dakotas becoming west over the Great Lakes then northwest over the northeastern CONUS. Additional moisture may be added for thunderstorm development when these systems move across Lake Ontario and Lake Erie. This regime generally produces a severe thunderstorm event, especially when these short waves enter the CONUS during the heating hours.

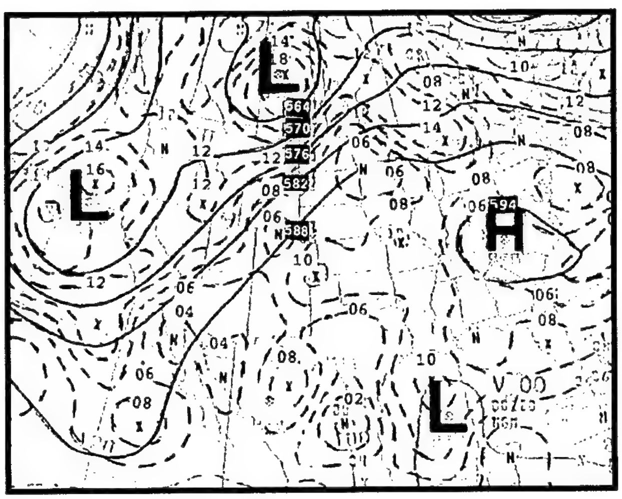


**Figure 5-1. NGM 500-mb 00-Hour Heights/Vorticity, 0000Z/20 July 1987.** Subtropical high in place over the central Appalachians

The following photos, Figures 5-2 through 5-4, illustrate this idea. In Figure 5-2, the subtropical ridge is shown over the central Appalachians. A short wave and its accompanying thunderstorms are moving southeasterly into western New York as noted by the arrow (no cold front was identified with this system). Another thunderstorm area appears over the Dakotas as shown by the arrow. Fifteen hours later, Figure 5-3, the Dakota thunderstorm area has grown as it moves across the northern Great Lakes (shown by the arrow).

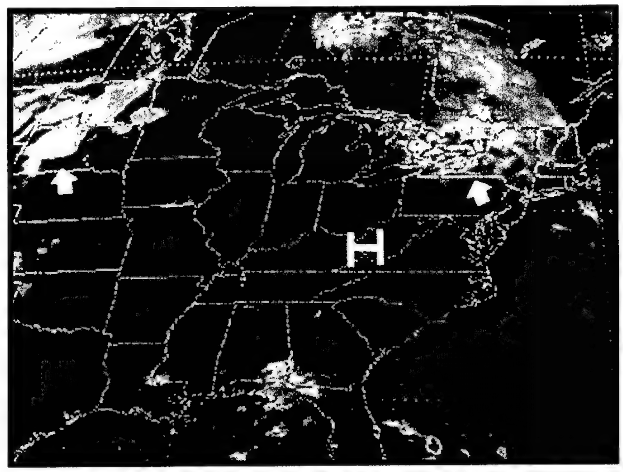


**Figure 5-2. Infrared (MB), 0553Z/20 July 1987.** Thunderstorms associated with short waves

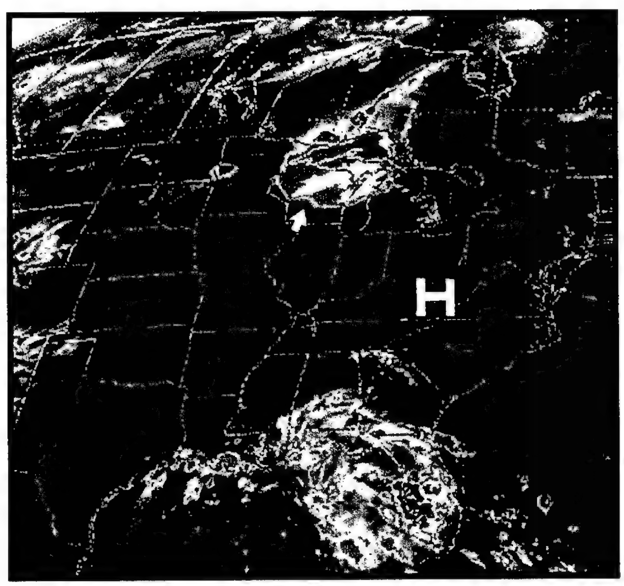


**Figure 5-3. Infrared (MB), 2052Z/20 July 1987.** Thunderstorm complex over Great Lakes.

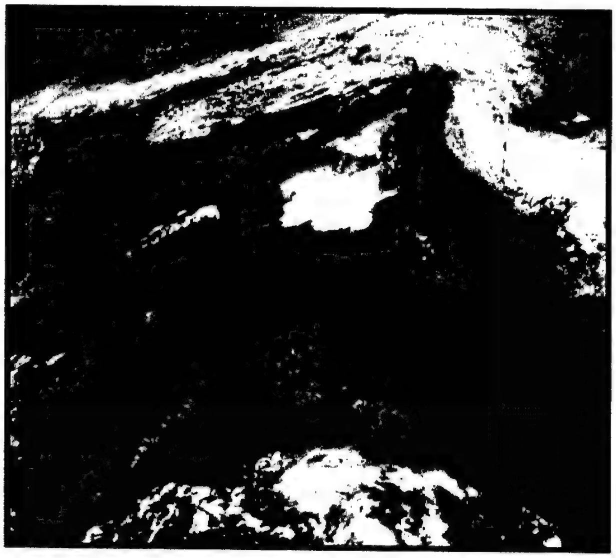

**Figure 5-4a. Visible, 1907Z/20 July 1987.** The figure shows a large cluster of thunderstorms over the Great Lakes.

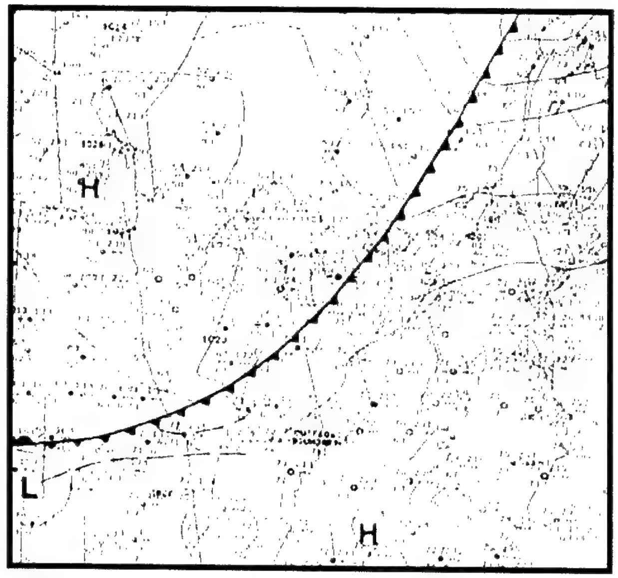


**Figure 5-4b. Surface Analysis, 1200Z/17 July 1999.** Cold front approaching East Coast.

Approximately 40 severe reports were reported over eastern Minnesota and northern Wisconsin during the day (Figure 5-4a). Thunderstorms continued eastward then dipped southeastward towards western New York. In Figures 5-3 and 5-4a, notice that a large area of the eastern CONUS, located under the subtropical high, shows clear conditions or small cumulus streets—this area is capped.

Fast-moving, inactive cold fronts, which drop southeastward from Canada or the Great Lakes, often produce squall lines and severe thunderstorms over the moist and unstable areas of the eastern CONUS especially if a northwest flow prevails (Figure 5-4b). July and August are the severe thunderstorm months for the New England area. Likewise, northeast-southwest oriented cold fronts occasionally decelerate and become stationary over the northeastern CONUS and produce widespread daily thunderstorms including severe thunderstorm events.

**East-West Stationary Fronts.** A more common frontal structure and alignment during the summer months is shown in the surface analysis in Figure 5-5. Canadian cold fronts move across the northeastern CONUS then trail back east-west across the Ohio and Tennessee valley areas and westward as shown in Figure 5-5 due to upper-level ridging across the southern CONUS. The visible satellite photos shown in Figures 5-6 and 5-7 illustrate two typical frontal alignments during the summer. Overrunning precipitation with embedded severe thunderstorms and heavy rainfall are likely to occur along these stationary fronts as maritime tropical moisture advects over these boundaries.

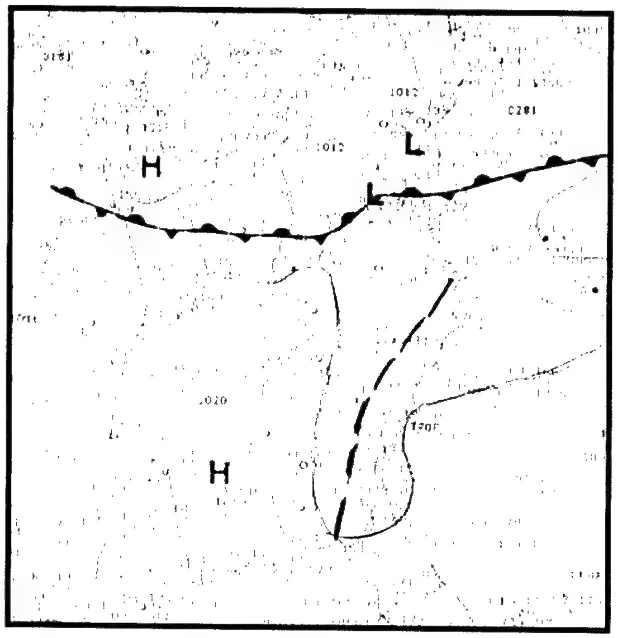


**Figure 5-5. Surface Analysis, 0000Z/23 July 1999.** Stationary front over northeastern CONUS. Notice lee-side trough North Carolina/Georgia (will be presented later).

**Figure 5-6. Visible, 1531Z/29 July 1982.** East-west stationary front.

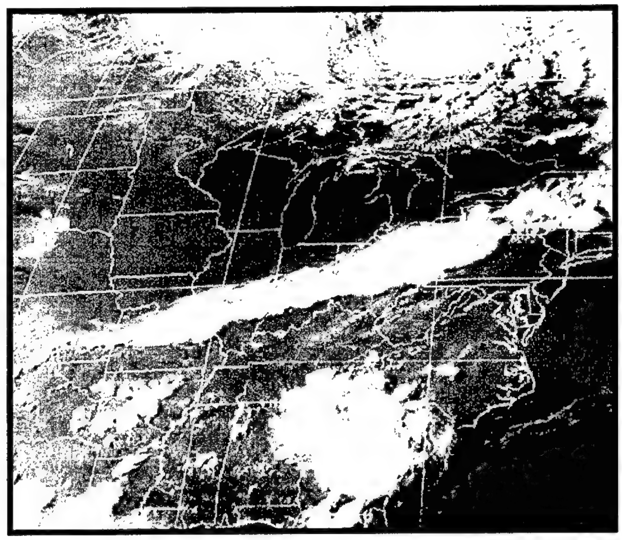

**Figure 5-8. Visible, 2232Z/6 July 1999.** Severe thunderstorms occurred along the front from the East Coast to Kansas.

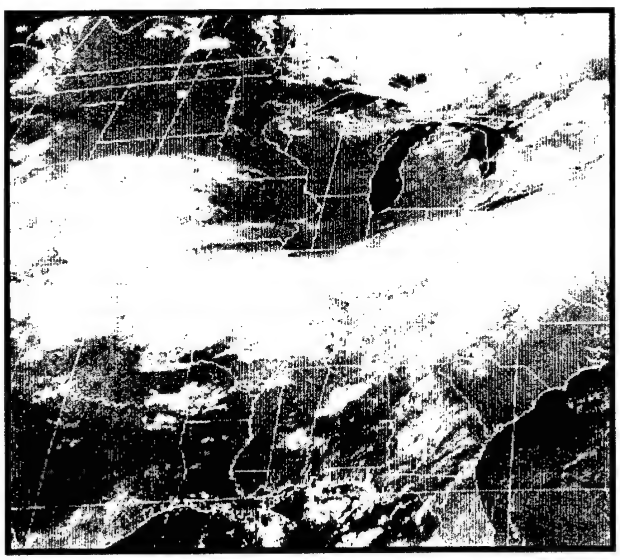

**Figure 5-7. Visible, 1430Z/23 July 1998.** Stationary front across eastern and central CONUS.

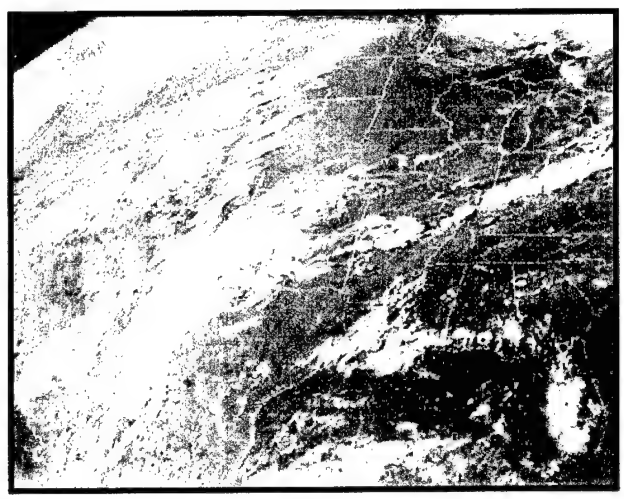

**Figure 5-9. Visible, 2230Z/18 June 1984.** The figure illustrates the occurrence of summer thunderstorms along a stationary front extending from Arkansas to Ohio.

Figures 5-8 and 5-9 illustrate two more occurrences of summer thunderstorm activity along stationary frontal systems that stretched from the East Coast to the central Great Plains.

**Upper-Level Northwest Flow.** Severe thunderstorms often occur in the summer along fronts from the Ohio Valley/Great Lakes eastward to the East Coast when mid-troposphere northwest flow prevails. Figure 5-10 illustrates a model (developed from case studies) of surface and upper-level features favorable for severe thunderstorm outbreaks along and north of warm or stationary fronts. In the model, the 500-mb wind flow is indicated by the dashed lines; the flow is generally from the northwest. The low-level wind flow is generally from a southerly component; mid-troposphere wind flow is from a northwesterly direction that establishes excellent vertical shear. Surface high-pressure systems track eastward across the Great Lakes and southern Canada since the steering winds are from the west or northwest. These frontal systems eventually become stationary over the Ohio Valley area as shown in Figure 5-10. Frontal waves develop with the approach of an upper-level disturbance and move down the stationary front. The air mass south of the front is moist and unstable; often east-west thermal and moisture axes are pooled up along the stationary front. With the approach of the frontal wave and its upper support, overrunning thunderstorms will develop along and north of the frontal convergence zone as the low-level jet transports moisture and heat over the front. This pattern is a summer severe thunderstorm scenario. Two examples will be shown.

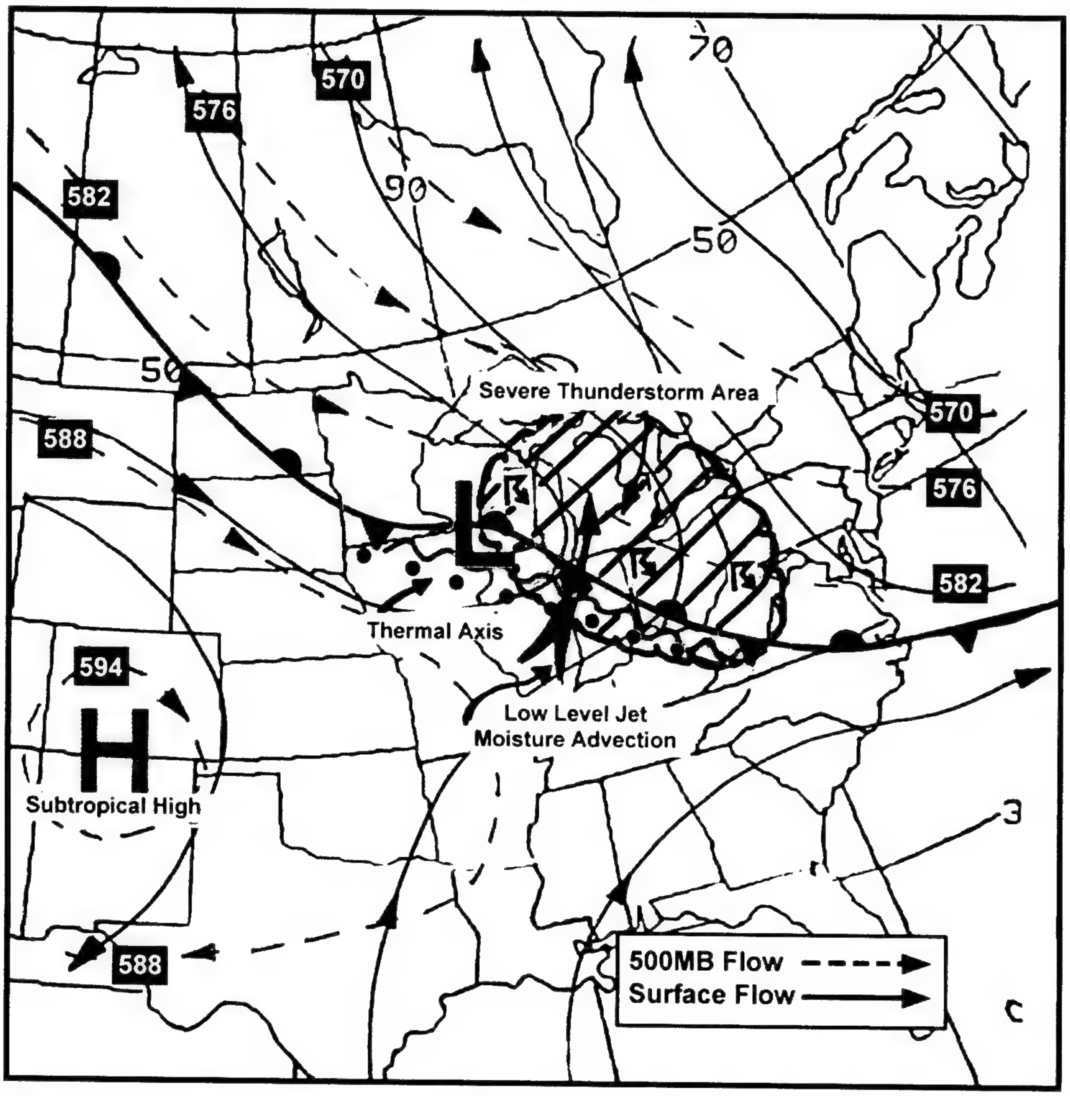


**Figure 5-10. Severe Thunderstorm Model.** This figure portrays the model for severe thunderstorm activity in the upper Midwest.

***Example 1:*** Figure 5-11 shows a mid-morning analysis depicting a stationary front from Ohio to the central Great Plains. A severe thunderstorm outbreak occurred over Minnesota, Wisconsin, northern Iowa and Illinois during the day (Figure 5-12). Twenty-four hours later, a severe thunderstorm outbreak occurred across Ohio and Pennsylvania as a small short wave, Figure 5-13, and a frontal wave, Figure 5-14, moved across the Great Lakes. Weak upper-level impulses should not be ignored; they often ignite severe thunderstorm outbreaks within an unstable, moist and heated air mass.

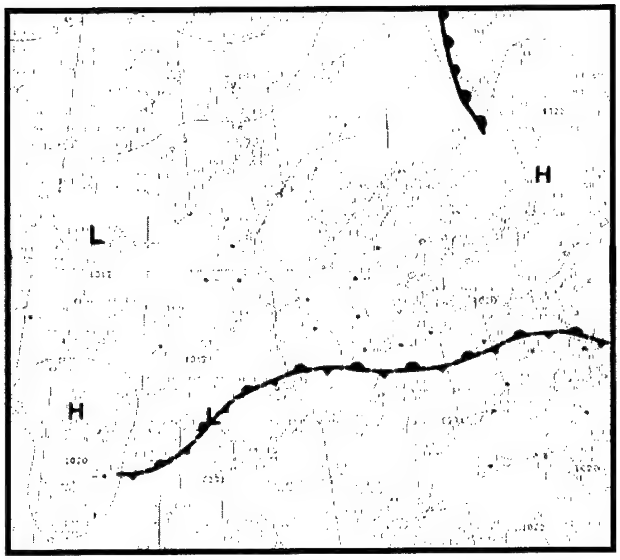


**Figure 5-11. Surface Analysis, 1200Z/20 July 1999.** Stationary front.

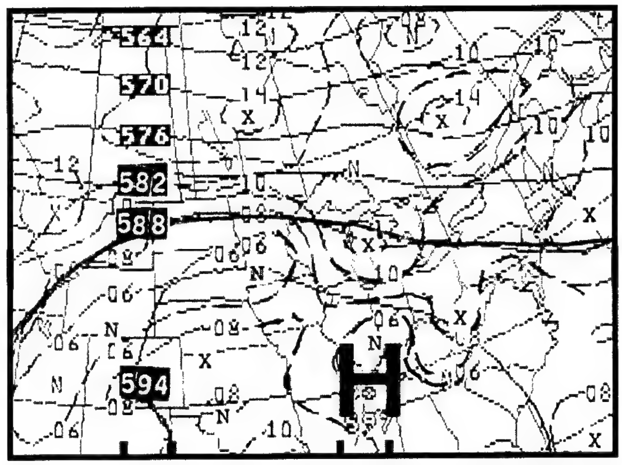


**Figure 5-13. NGM 24-Hour HEIGHTS/VORTICITY 0000Z/22 July 1999.** Short wave over the Great Lakes

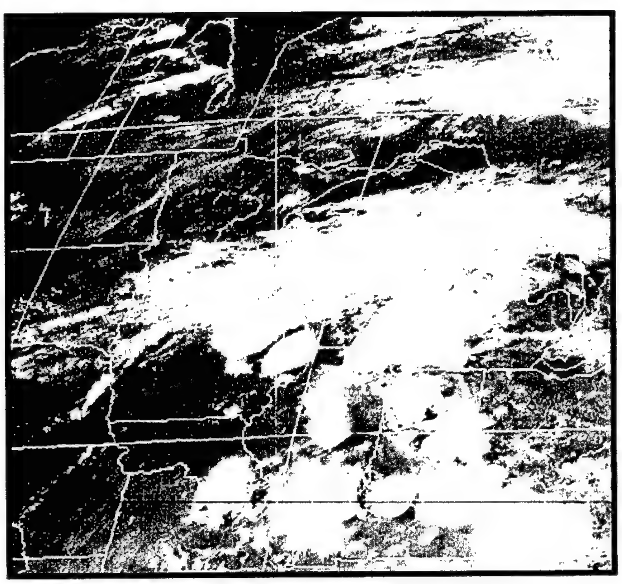

**Figure 5-12. Visible, 2245Z/20 July 1999.** Large thunderstorm area, upper Midwest, associated with short wave.

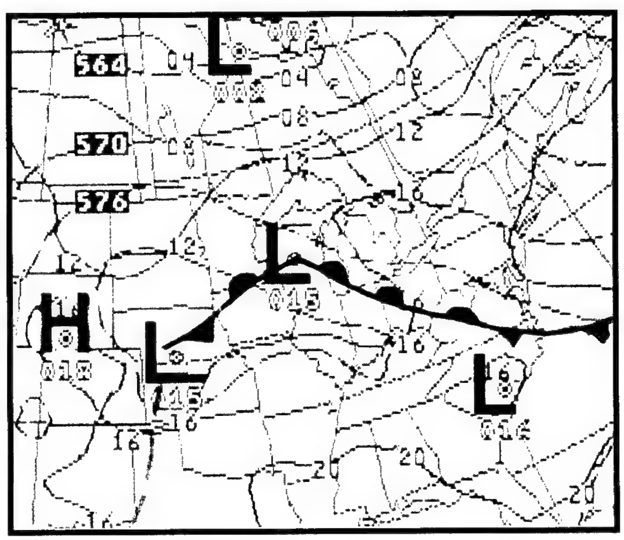


**Figure 5-14. NGM 24-Hour Mean SLP/1000-500-mb Thickness, 0000Z /22 July 1999.** Frontal wave/ warm front associated with short wave.

***Example 2:*** Figures 5-15 and 5-16 reveal a line of thunderstorms, which developed along an Ohio Valley stationary front. No conventional data was available, but the reader can surmise where the boundary lies by the cumulus streets (noted by the arrows in Figure 5-15). The high-pressure system is most likely located over the upper Great Lakes. A west-to-north mid-level flow is likely based on satellite interpretation. Another short wave appears over the Dakotas and strong thunderstorms have developed. In Figure 5-15, a scattered line of enhanced cumulus has developed over central Illinois and Kentucky.

**Figure 5-15. Visible, 1828Z/28 July 1989.** Enhanced cumulus along stationary front over Ohio Valley.

Less than three hours later, Figure 5-16, a nearly solid line of thunderstorms has developed along the frontal boundary. Air mass thunderstorms are located south of the boundary across the Tennessee Valley.

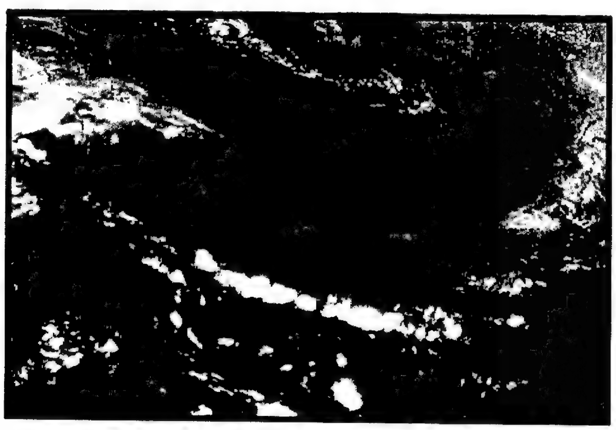

**Figure 5-16. Visible, 2058Z/28 July 1989.** Thunderstorms have developed along frontal boundary.

Because of increased ridging and the northward shift of the jet stream, there will be fewer occurrences of cold fronts across the southern CONUS during the summer. An upper-level ridge west of the Mississippi River and a trough east of the Mississippi River almost always supports cold fronts that make it into the deep south over the eastern CONUS. With a cooler air mass penetrating southward into the moist, unstable air over the Gulf Coast (Figure 5-17), widespread thunderstorms and heavy precipitation are likely as shown in the radar summary chart (Figure 5-18; 12 hours later from Figure 5-17).

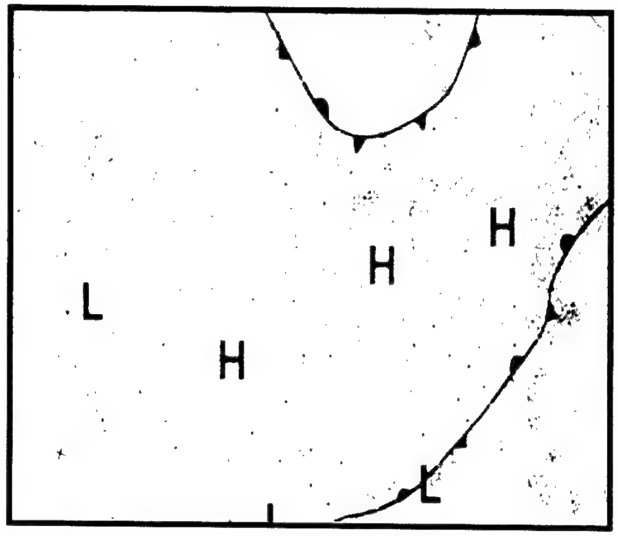


**Figure 5-17. Surface Analysis, 1200Z/19 July 1979** Cold front push deep into southern CONUS.

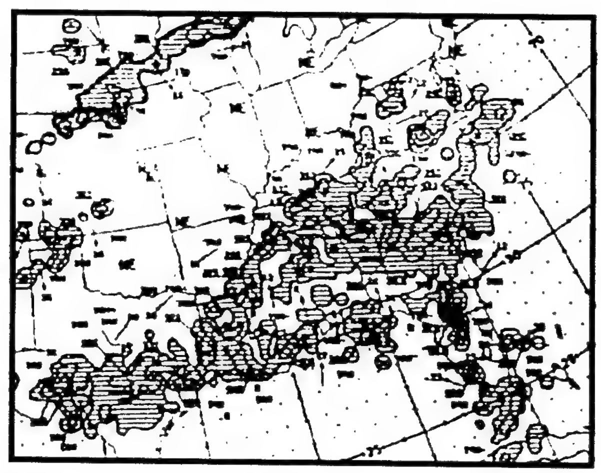

**Figure 5-18. Radar Summary Chart, 2335Z/19 July 1979.** Extensive thunderstorm/rain showers developed during the heating hours as the front became stationary.

A second example of frontal thunderstorms along the Gulf Coast is shown in Figure 5-19. Severe thunderstorms occurred all along the front especially over Arkansas, northern Louisiana and southern Mississippi.

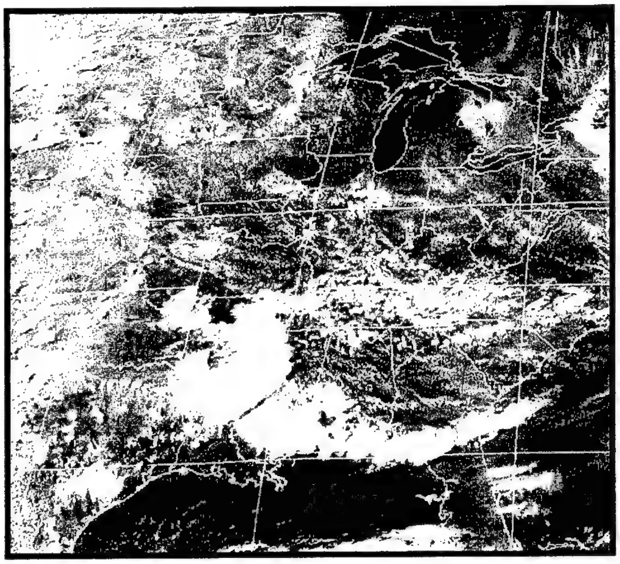

**Figure 5-19. Visible, 2215Z/1 July 1998.** Cold frontal thunderstorms stretch across the Gulf Coast.

A third example of cold frontal convection over the Gulf Coast is shown in this mid August visible photo, Figure 5-20. Besides gulf coast convection, cold fronts that move across the Appalachian Mountains into the lee-side trough, usually a hot, moist and unstable air mass,

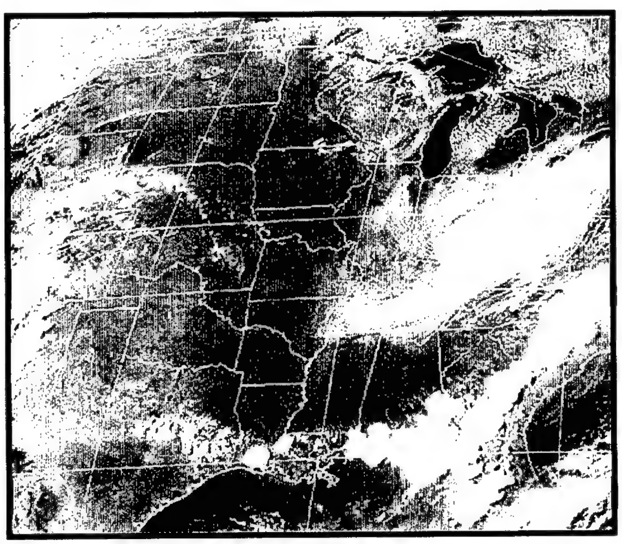

**Figure 5-20. Visible, 2045Z/14 Aug 1999.** Extensive frontal thunderstorm line east of the Appalachian Mountains.

will be the trigger for rapid thunderstorm development (often severe thunderstorm events; see Figure 5-22). In Figure 5-20, a strong, organized, frontal thunderstorm line is noted from Virginia to eastern Georgia. Eighty-six severe thunderstorm reports, including two tornadoes, were reported between 1800Z and 0000Z within this line. More severe thunderstorms occurred along the gulf coast from the Florida Panhandle to southern. Alabama.

Forecasters located in the southern CONUS should monitor cold fronts that have modified and become stationary (Figure 5-21); there may just a slight difference in surface temperatures and dew points but enough convergence still exists for the production of thunderstorms during the heating hours. East-west surface troughs are sometime depicted on surface analyses (instead of fronts) as the air mass modifies (Figure 5-21).

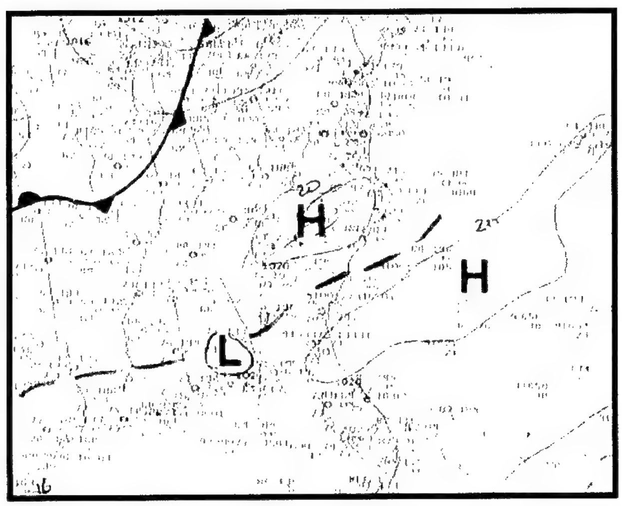


**Figure 5-21. Surface Analysis, 0900Z /17 Aug 1999.** Old frontal boundary across the southeastern CONUS.

**Air Mass/Lee-Side Thunderstorm.** The Appalachian Mountain's lee-side trough that extends from the northeastern CONUS to Georgia is often moist and unstable throughout the summer months; surface dew points are generally above 70° F (Figure 5-22). Air mass thunderstorms occur often during the heating hours. Forecasters should pay attention to developing cumulus lines over the Appalachians that may be associated with a weak upper-level disturbance and/or a surface boundary. Severe thunderstorms are likely when these thunderstorms organize over the mountains and move

into the heated, moist, unstable lee-side trough. (see Figure 5-20.) Afternoon severe thunderstorms, mainly hail and wind damage, were reported from Massachusetts to Virginia. Mesoscale surface lows may appear within the lee-side trough—these lows should be monitored for potential severe thunderstorms and tornadoes.

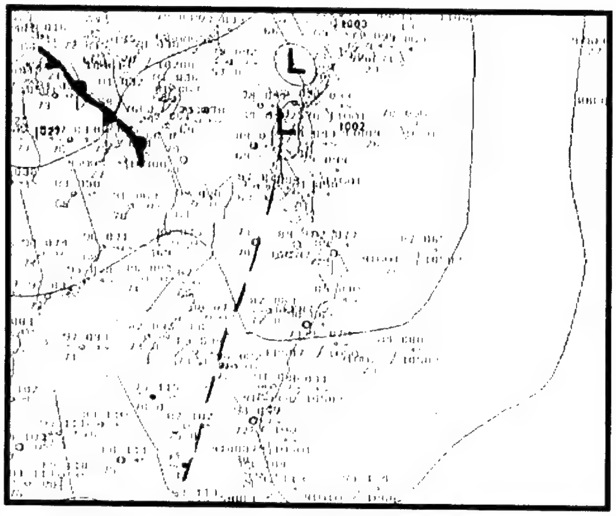

**Figure 5-22. SurfaceAnalysis, 0000Z/30 July 1999** A weak surface trough is shown over the eastern CONUS

Isolated air mass severe thunderstorms will occur daily somewhere over the southeastern CONUS throughout the summer. Severe thunderstorms are likely in the late afternoon as the convection matures; infrared satellite photos and Doppler radar will aid in the determination of collapsing tops that often produce hail and strong surface winds. The mountainous areas of northern Georgia and Alabama often produce small, unorganized severe thunderstorm outbreaks as they move southward off the mountains. In Figure 5-23, an area of enhanced convection appears over northern Georgia and Alabama (noted by the arrow). Likewise, locations east of the Appalachian Mountains of Virginia and the Carolinas, can expect isolated non-frontal severe thunderstorms. Forecasters should pay attention to any mid-level, small cold pockets that appear on the 1200Z 500-mb analysis. Considering that all surface parameters are in place for convection, cold pockets will steepen lapse rates and subsequently a severe thunderstorm outbreak is likely.

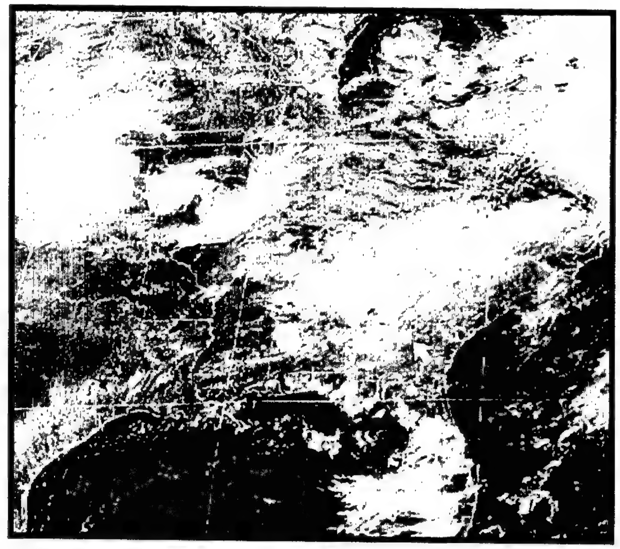

**Figure 5-23. Visible, 2010Z/08 July 1998.** Enhanced convection over northern Georgia and Alabama.

Nocturnal thunderstorms (non-frontal) occur frequently over the warm waters of the Gulf Stream, typically 50-100 miles from the North and South Carolina coastal area throughout the summer.

Although not as frequent as daytime sea breeze convection, nocturnal land breeze-induced thunderstorms may occur along the immediate North and South Carolina coastal waters as well as along the Gulf of Mexico coastal areas. The IR photo, (1200Z; Figure 5-24), shows thunderstorms along the South Carolina coast and also off the coast of the Florida Panhandle (noted by the arrows). No history of these thunderstorms was available.

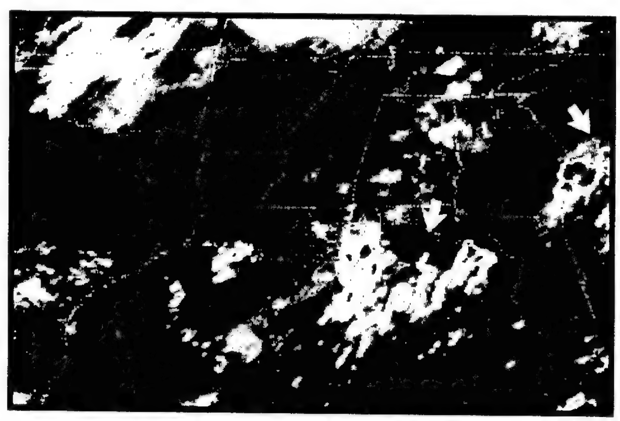

**Figure 5-24. Infrared (MB), 1201Z/18 July 1982.** Land breeze offshore thunderstorms noted by the arrows.

The 500-mb and surface chart (1200Z) are shown in Figure 5-25 and 5-26, respectively. At the 500-mb level, the subtropical high prevails with light southerly winds over the southeastern CONUS. At the surface, Figure 5-26, no frontal systems were located over the coastal areas. Land breeze thunderstorms form most often during the early morning hours (0400-1000Z) within 20 miles of the coast and often developed explosively, and at times produced large hail, frequent lightning and strong winds.

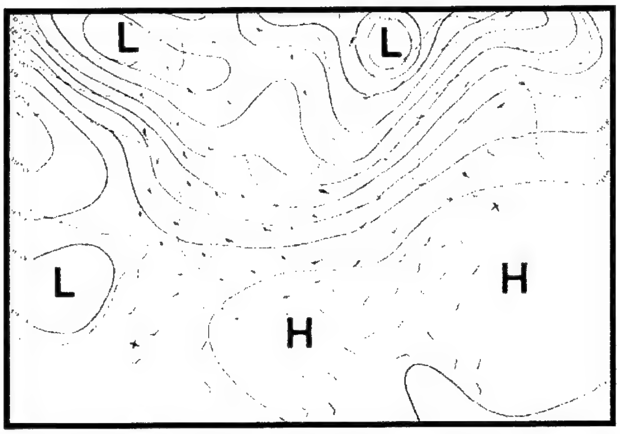


**Figure 5-25. 500-mb Analysis, 1200Z/18 July 1982.** Subtropical high prevails across the southern CONUS.

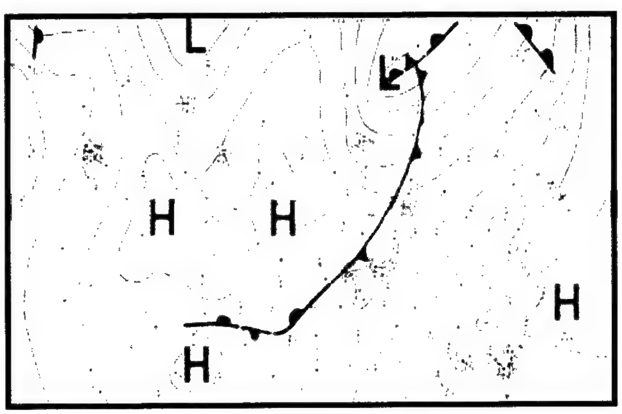


**Figure 5-26. Surface Chart, 1200Z/18 July 1982.** Subtropical ridge extends across the southern CONUS

It was presented earlier in the central CONUS discussion that convection occurs on the southern side of the subtropical ridge (usually over the northern Gulf of Mexico) where mid-level temperatures are cooler than the temperatures over the heated land. Sea breeze activity over the coastal areas, and at times, westward moving surface troughs over the Gulf will produce widespread convection. See previous discussion and illustrations in Chapter 4, Figures 4-76 through 4-78.

The occurrences of sea breeze thunderstorms within southerly gulf flow can be expected throughout the summer from the Florida Panhandle westward to the east coast of Texas (Figures 5-27 and 5-28). Frontal intrusions would temporarily affect sea breeze activity over the Gulf Coast. Figures 5-27 and 5-28 illustrate sea breeze activity. The early afternoon visible photo (Figure 5-27; early July) shows convection enhancing over southern Georgia westward to southern Louisiana. Five hours later, Figure 5-28, mature thunderstorms extend across the entire region.

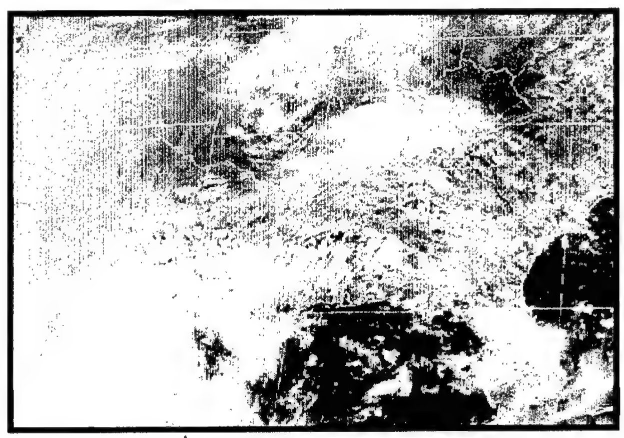

**Figure 5-27. Visible, 1846Z/03 July 1998.** Sea breeze convection extends inland across the Gulf Coast.

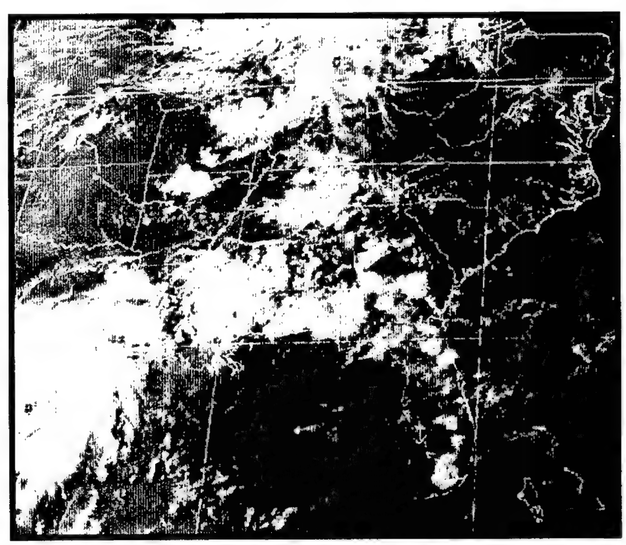

**Figure 5-28. Visible, 2315Z/03 July 1998.** Five hours after Figure 5-27, mature sea breeze thunderstorms extend inland across the Gulf Coast.

The Florida Peninsula's monsoon season continues through the summer. Sea breeze convection develops by mid-morning and widespread thunderstorms affect the peninsula by early afternoon. Sea breeze development during the heating hours across the peninsula is almost a daily occurrence throughout the summer (Figure 5-29).

In Figure 5-29 sea breeze thunderstorms are shown across the Gulf Coast States and the northern Gulf of Mexico. Notice the direction of the cirrus anvils over mainland Florida; the cirrus plumes are blowing from northeast to southwest indicating the subtropical high is located somewhere to the north. Depending on the direction of the low-level flow, a sea breeze will develop either on the east side and/or the west side of the peninsula. Thunderstorms develop quickly within the sea breeze convergence zone over the interior areas of the peninsula. Predominate offshore wind flow would retard local sea breeze development. Undoubtedly, peninsula forecasters have good local rules for forecasting the location and onset of sea breeze thunderstorm activity.

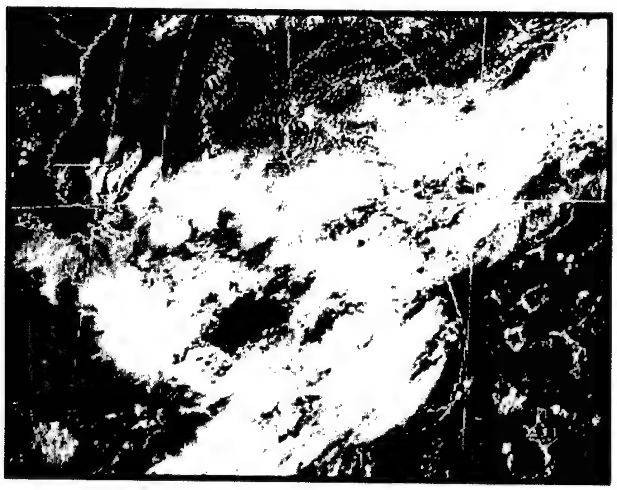

**Figure 5-29. Visible, 2145Z/01 August 1998.** Extensive daytime thunderstorms over the Florida Peninsula and eastern Gulf Coast.

In another example, the visible satellite photo shown in Figure 5-30 depicts sea breeze thunderstorms over a large area of the peninsula. The related 1200Z 500mb and surface analyses are shown in Figures 5-31 and 5-32 respectively. Notice in Figure 5-31 the wind flow is from an easterly direction across Florida due to subtropical ridging to the north. The surface features in Figure 5-32 show that the eastern CONUS is under the Bermuda ridge: easterly surface wind flow from the Bermuda ridge extends across Florida. In the satellite picture, Figure 5-30, sea breeze convection developed in the interior area on the peninsula's east side. Most thunderstorms are in the general thunderstorm category (=35 knots/¾ inch hail), but several isolated severe thunderstorms can occur by late afternoon. The Orlando to Tampa corridor is notorious for daily thunderstorms and heavy rainfall. This corridor experiences more occurrences of severe thunderstorms then anywhere else on the peninsula. An easterly flow from the surface to the midlevel is established when the subtropical ridge/

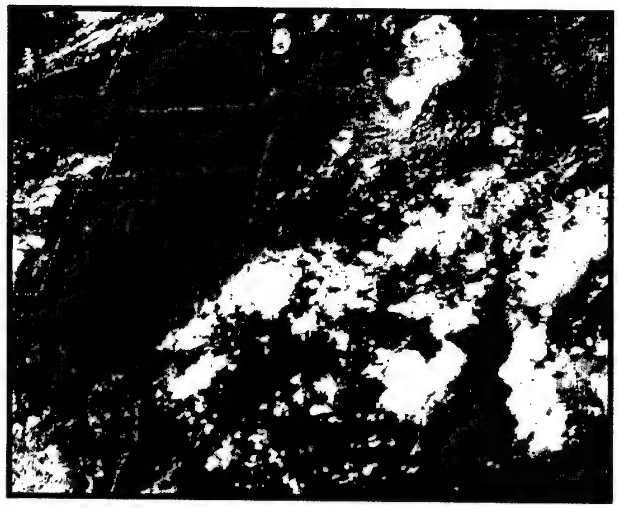

**Figure 5-30. Visible, 2030Z/16 July 1982.** Sea Breeze thunderstorms over Florida.

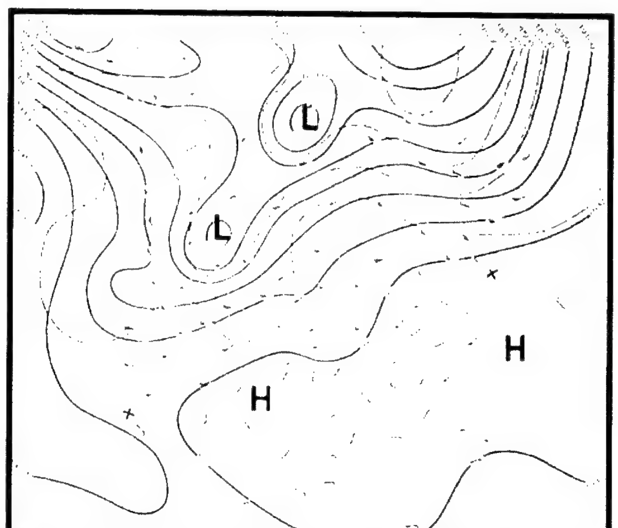


**Figure 5-31. 500-mb Analysis, 1200Z/16 July 1982.** Easterly mid-level wind flow over Florida.

high is located to the north of Florida. Minor perturbations (or inverted surface troughs) approaching Florida from the east will bring periods of thunderstorms with heavy rain across Florida. These systems must be carefully monitored because they may develop into tropical storms during late summer.

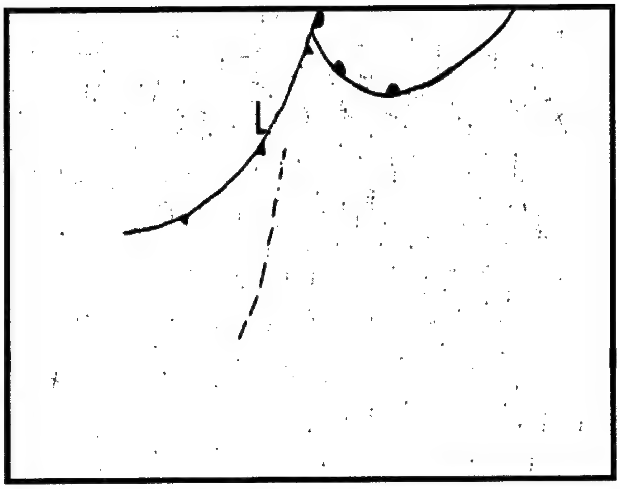


**Figure 5-32. Surface Analysis, 1200Z/16 July 1982.** Easterly surface/low-level flow prevails over the southeastern CONUS.

**Atlantic and Gulf of Mexico Tropical Activity.** All Atlantic and Gulf of Mexico lows should be monitored for tropical storm development. Tropical storms may occur as early as June, however, the greatest threat begins in mid-July, and continues through September with most activity in August and September. Less frequent tropical storm activity occurs in October and early November. Forecasters should monitor all disorganized, deep convective cloud systems that appear offshore such as shown in Figure 5-33 across the eastern Gulf of Mexico. In Figure 5-34, 22 hours later, some organization is noted within the Gulf system; it appeared on the surface charts as a weak low. Fortunately, this system remained a tropical depression as it moved slowly towards Texas.

Weak tropical depressions such as shown in Figures 5-33 and 5-34 may still be dangerous to inland locations lying within its path. The associated moisture and instability spread inland (combined with heating and rising terrain) and trigger thunderstorms, tornadoes and heavy rainfall over a large region (Figure 5-35). The remnants of a hurricane can spread havoc far into the interior over a period of several days.

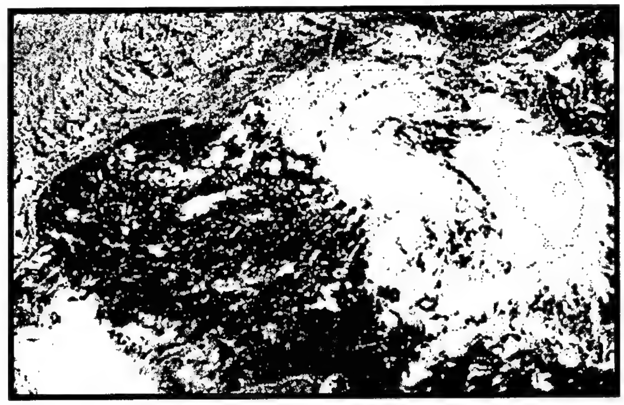

**Figure 5-33. Early September Visible, 1930Z.** Suspicious, deep convective system in the eastern Gulf.

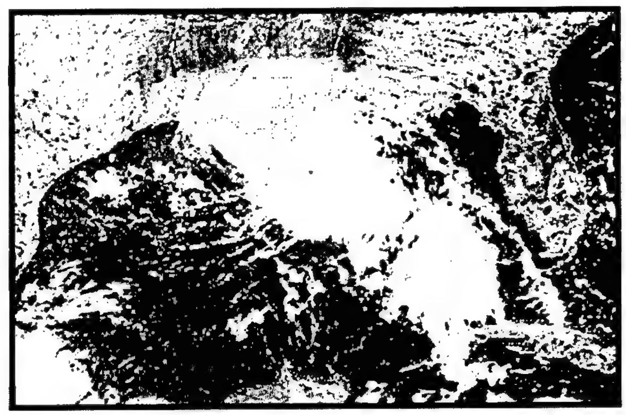

**Figure 5-34. Next Day Visible, 1730Z.** Large convective system moving slowly westward.

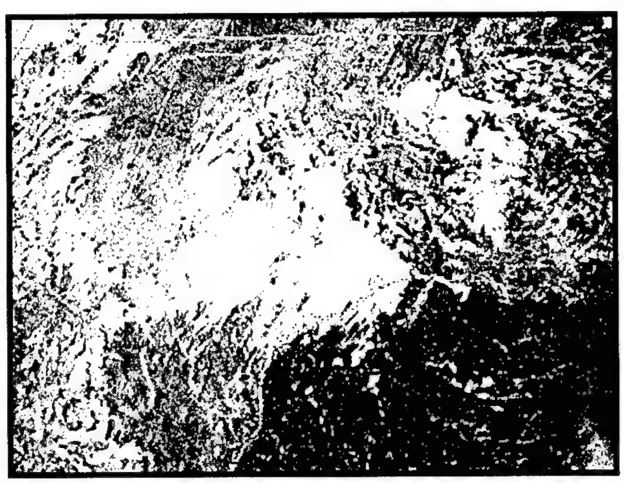

**Figure 5-35. Early September Four Days Later, 1930Z.** Tropical depression has moved inland across eastern Texas and Louisiana. Heavy rains and flash flooding occur with these systems.

Tropical waves, often depicted as inverted troughs on surface charts, may move westward across Florida into the Gulf of Mexico and towards Louisiana and Texas (Figure 5-36). The waves are accompanied by thunderstorms and heavy rain showers and may trigger a tropical depression. In Figure 5-37, the cloud mass indicated by the arrow produced a tropical storm (two days later from Figure 5-36).

Tropical storms can spawn severe thunderstorms and flash floods over land well away from the storm's center. The radar summary chart, Figure 5-38, depicts the effect that a tropical storm (shown in earlier in Figure 5-37) caused over a large area of the eastern one-third of the CONUS.

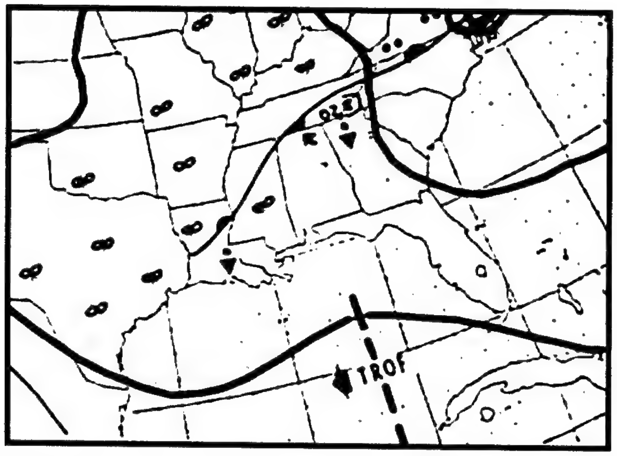


**Figure 5-36. Surface Analysis Mid-July, 1500Z.** Surface trough with inverted isobars.

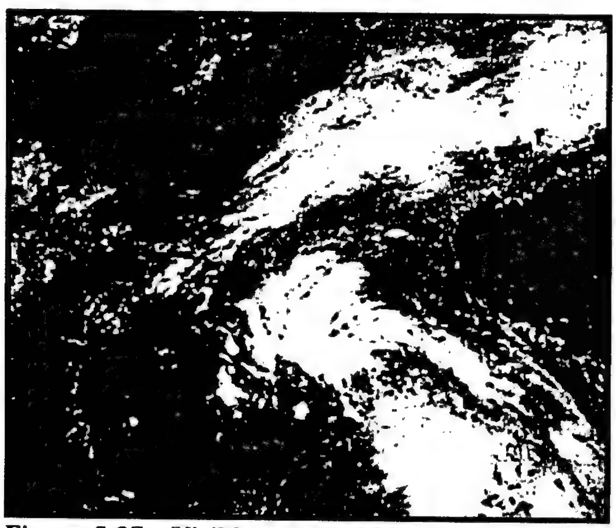

**Figure 5-37. Visible, 1517Z/Mid-July.** Related to Figure 5-36.

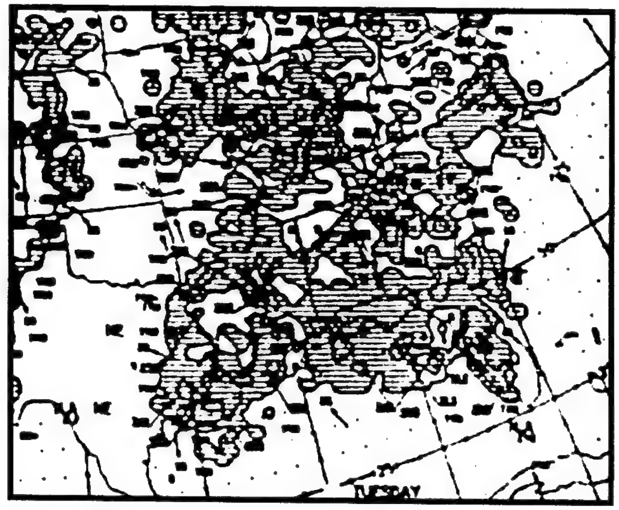

**Figure 5-38. Radar Summary Chart, 2135Z.** Three days later from Figures 5-37 and 5-38.

Atlantic and Gulf coast forecasters should be aware that disturbances located close to the coast might evolve into a tropical depression or storm within a period of several days or less. Figures 5-39 and 5-40 illustrate an event along the Texas gulf coast. In Figure 5-39, a disorganized area of convection is shown over the western Gulf of Mexico. Over the next four days the tropical system became organized and was named Tropical Storm Charley (Figure 5-40). Charley moved slowly into eastern Texas and dissipated over south central Texas. Heavy rains fell over southern Texas; Laredo and Del Rio received heavy rainfall.

**Figure 5-39. GOES East Visible, 1632Z/18 August 1998.** A disorganized area of thunderstorms is located in the western Gulf.

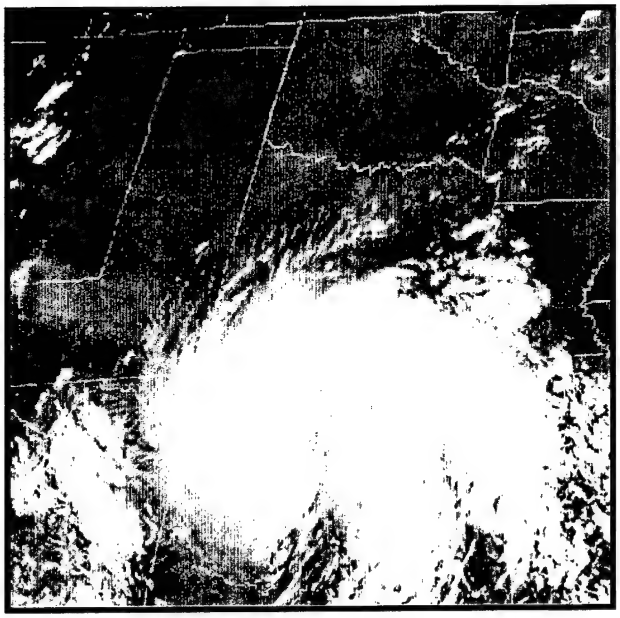

**Figure 5-40. GOES East Visible, 1432Z/22 August 1998.** Four days later, the tropical system was named Tropical Storm Charley

Two additional pictures of Gulf tropical systems are shown in Figures 5-41 and 5-42 (different days).

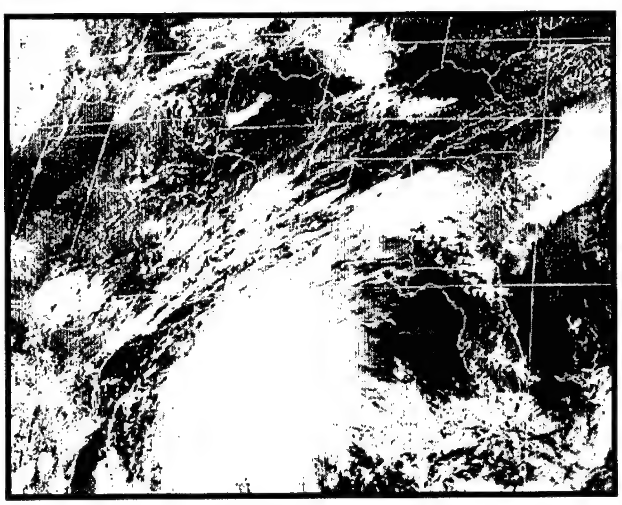

**Figure 5-41. Visible, 2145Z/31 August 1998.** A tropical system is located over the central Gulf of Mexico.

The appearance of westerly moving hurricanes over the south Atlantic Ocean begins in August as illustrated in Figure 5-43, a late August picture. The threat of hurricanes affecting the eastern CONUS continues through October.

**Figure 5-42. Visible, 2302Z/21 August 1999.** Hurricane Bret approaches southern Texas and Mexico (not related to Figure 5-41).

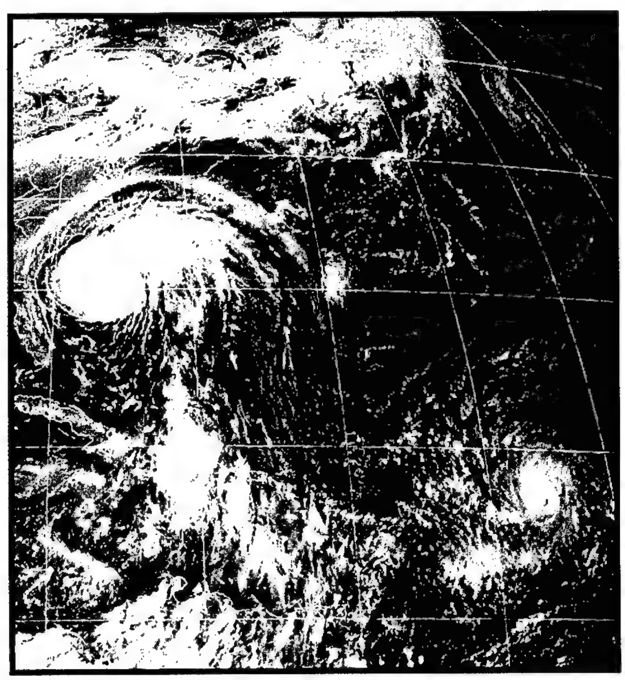

**Figure 5-43. Visible, 2015Z/25 August 1998.** Hurricane Bonnie approaches the Carolinas. Hurricane Danielle organizies over the Atlantic Ocean.

Figures 5-44 and 5-45 depict two separate September hurricanes that affected areas of the East Coast. Finally, towards the end of summer, the subtopical ridge begins to shift southward. In response the polar jet sinks southward and a return to autumn-like weather commences by the end of September.

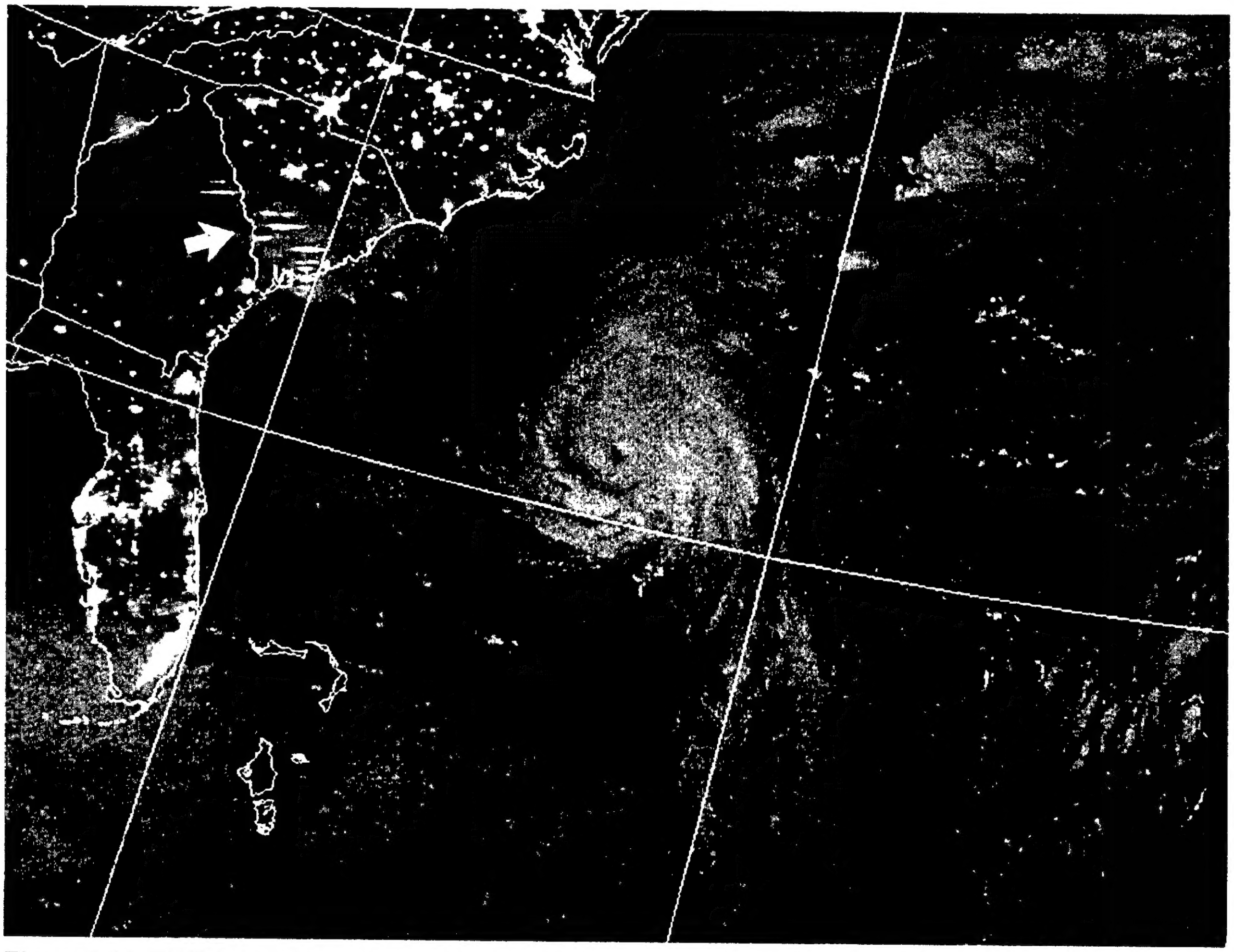

**Figure 5-44. DMSP, 0059Z/01 September 1999.** Hurricane Earl approaches the southeastern CONUS. Lightning strikes are noted over southern South Carolina (see arrow).

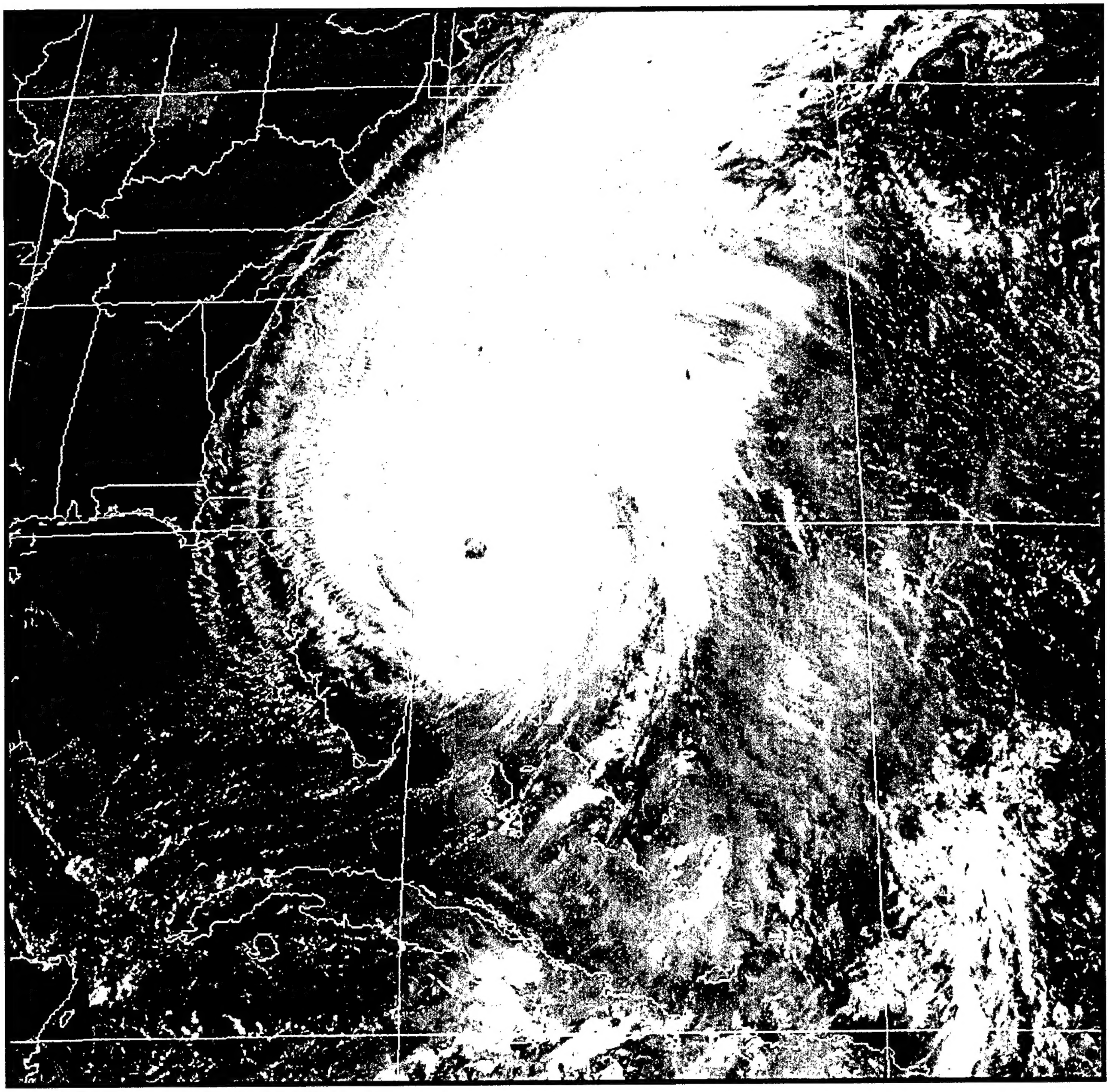

**Figure 5-45. Early Morning Visible, 1215Z/15 September 1999.** Hurricane Floyd nears the Florida and Georgia coastline.

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# ATTACHMENT 1

## HEAVY CONVECTIVE PRECIPITATION DURING THE SUMMER MONTHS

Sometime during the summer months, one or more weather units may be affected by heavy downpours which could persist for several hours. These heavy rains are often unforecast although a local thunderstorm met watch or weather warning may be in effect. The trigger mechanism(s) which often are responsible for summer heavy rains are generally mesoscale features that may not be forecast by numerical weather prediction progs. Additionally, surface and upper level synoptic-scale features that trigger heavy rainfall are often weak and may go unnoticed by both the progs and forecasters.

The presence of plentiful summertime moisture is evident daily from the precipitable water panels of NWS's composite chart (Figure 1). Precipitable water values often exceed one inch and, in some instances, two inches. High precipitable water values can extend westward from the southern Plains across New Mexico towards Arizona, Utah and Nevada during July when surges of hot, moist tropical air replace dry, continental air.

Pockets of unstable air are also observed daily on the composite's Lifted Index/K Index panel throughout the summer months (Figure 2). With plentiful moisture available and the presence of unstable air, how would forecasters be able to recognize and predict heavy rainfall? Would forecasters be lulled into not paying as much attention to these two parameters during the hot, muggy summer months, when, in many cases, isolated precipitation or none at all occurs? Forecasters should always be on the alert for the trigger mechanism(s) necessary to produce heavy rainfalls (see below).

The following information is presented to aid forecasters in recognizing conditions favorable for heavy persistent convective rainfall. Portions of this information were extracted from various NWS publications pertaining to flash flood forecasting.

### TRIGGER MECHANISMS

*Surface/Lower* Level
- Heating Differential
- Low Level Jet/Convergence Zones
- Orographic Lifting
- Weak Troughs/Lows
- Quasi-stationary Fronts (includes slow-moving warm/cold fronts)

+ High Moisture Values +

*Upper Level*
- Contour Trough (often weak)
- Thermal Trough (often weak)
- Cold Air Advection
- PVA
- Divergence

- Tropical Disturbances — Feeder Bands

### Features Common To Heavy Precipitation

Forecasters should be alert:
- for strong quasi-stationary echoes (little movement for two hours or more). Particular attention should be paid to echoes with tops above 35,000 ft, echoes taller than surrounding echoes by more than 5,000ft, also to rapidly growing and line echo wave patterns (LEWP).
- to heavy rain possibilities whenever thunderstorms are imminent or occurring, especially if the moisture content of the air at or below 700 MB is higher than average for the area and season (i.e. surface dew points are well above normal) and/or a lifting mechanism such as warm advection or positive vorticity advection at 500MB is present.
- that slow-moving thunderstorms often produce localized heavy rains over the western CONUS.
- that heavy rainfall occurs primarily at night.
- that organized mesoscale thunderstorm system can produce larger precipitation accumulations due to persistent and/or repeated cell development over a small area.
- that severe thunderstorms usually do not occur in the heavy rain areas.
- that storm areas are very near 500MB ridge positions.
- that weak mid-level short wave troughs moving through or around ridges help to trigger and focus storms.
- that quasi-stationary large scale frontal systems help to trigger and focus storms.

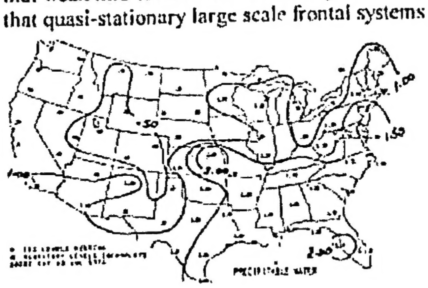

Figure 1

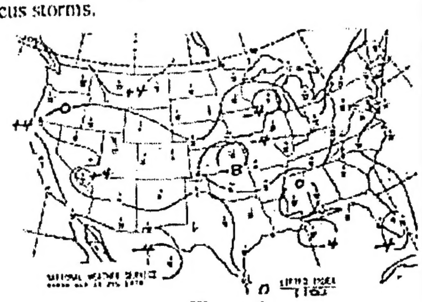

Figure 2